FIRST SCIENCE BOOK

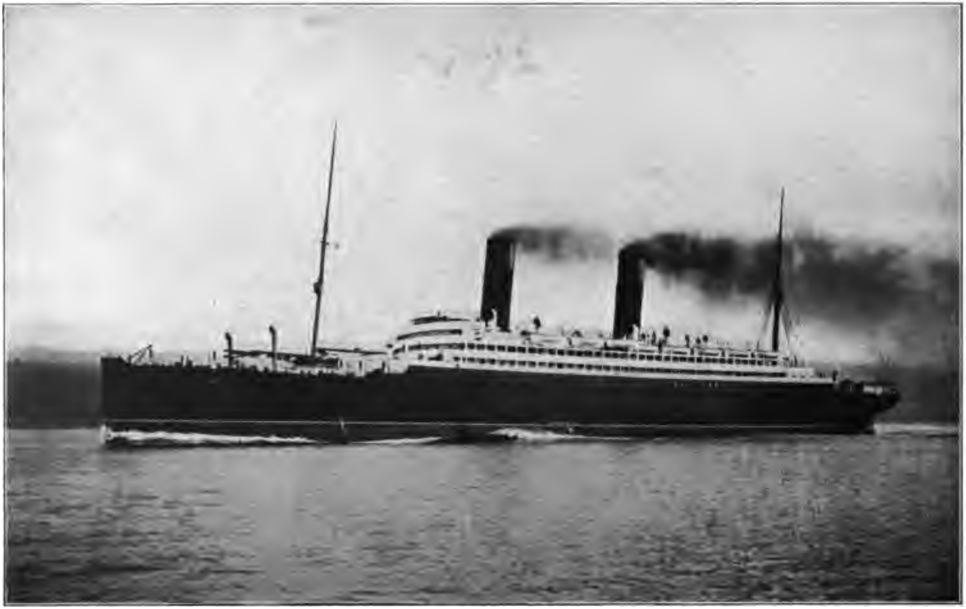

Plate I. One of the Largest Steamships in the World

FIRST SCIENCE BOOK

PHYSICS AND CHEMISTRY

BY

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PREFACE

This book is designed to serve as an introduction to scientific study, and at the same time to present a thorough course in the science of common phenomena. Whether the pupil has been prepared by courses in "nature study" or by his independent observation of things about him, he will find many subjects that are already known to him here treated in a manner which should explain the mysteries and clarify his ideas. Finishing this course, the pupil should be well fitted to take up the science studies of preparatory schools, and should have a store of serviceable knowledge.

In adapting methods and language to the view point of young pupils, the author has drawn upon an experience of several years with them. While it is one object of the book to teach the terms and expressions of science, care has been used to keep the meaning clear. Methods of treatment that easily convey wrong impressions have been avoided, as well as those which offend pupils of grammar school age. An effort has been made to show the practical bearing of the various subjects upon affairs in our daily experience, such matters being introduced wherever they may serve to illustrate or explain. The experiments are simple and may be performed by the teacher, or by the pupils with his oversight. Briefly, it is believed that the book will present a course which

shall be simple, interesting, and instructive, yet losing nothing of its accuracy.

The proof has been read by Professor G. F. Hull of Dartmouth College, for whose critical suggestions the author is very grateful. Several corporations and firms have kindly furnished photographs for the engravings as follows: General Electric Company, the dynamo; H. K. Porter Company, Pittsburg, Pennsylvania, the air locomotive; Baldwin Locomotive Works, the steam locomotive; Illinois Steel Company, the blast furnace; Cunard Steamship Company, the steamship.

LOTHROP D. HIGGINS

CLINTON, CONNECTICUT
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FIRST SCIENCE BOOK

PART I. PHYSICS

CHAPTER I

MATTER AND ENERGY

SECTION I

DEFINITIONS

1. Introduction.—It is important, in beginning a new study, to have some clear idea of what the study is to be. The word *science* may perhaps call to mind strange things of which we have heard, so that we think of it as the study of uncommon things. We shall find, however, that science treats of very common matters, many of which we already understand and most of which affect our daily lives. The main difference between scientific study and simply seeing things happen is a difference in the manner of doing it. Scientific study is orderly; each fact is studied in connection with others that are like it, thus making the whole more simple. In science we are not content to find that a thing does happen, but we try to find out how it happens, what causes it, and what is its effect upon other

happenings in turn. So then let us enter upon these studies resolved not only to learn all that we can but also to search deeply into each new fact until we fully understand it.

2. Physics.—It is easy to see that if science is the study of common things, it must include a great number of subjects that are very different from each other. In order to separate these subjects so that each may be treated more simply, scientific study is divided into many branches, such as physics, chemistry, botany, geology, and others. Still these branches are more or less related to each other, the teachings of one often being applied to several of the others; in fact, one could hardly know any of the sciences well without knowing something about one or more besides. The teachings of physics are perhaps most generally used, and for this reason it forms a natural starting point for our study.

In its broadest meaning, physics is the study of *matter* and *energy*. Concerning matter, physics treats of such changes as affect its forms and motions.

3. Matter.—To understand this definition it is necessary to know first what is *matter*. No one can really tell what matter is—it can only be described; and it occurs in so many forms and has such various features that no full description would apply to all sorts of matter. Some kinds are of one color and some another, while many show no color at all; different kinds vary in weight; there are hard substances and soft; and in many other ways we look in vain for features which

shall apply to all bodies. We find, however, that everything which we commonly consider to be matter occupies space or takes up room. Therefore, for want of a better definition, we may say that *matter is anything which occupies space.*

FIG. 1

Experiment 1. — Hold a tumbler bottom upward and push it into water, as in Fig. 1. What do you observe? What is in the tumbler before it is pushed downward? Does it take up room? Give a reason for your answer. Is air a sort of matter? Is there any form of matter that cannot be seen?

4. Natural Laws. — The word *law* as used in science has a meaning with which we may not be familiar. A *natural law* is simply a statement of a happening as it occurs in nature. Such laws are not made by man. From time to time men may find out new ones by studying nature, and they may state them for the first time; but no man can make a natural law or destroy one. Doubtless there are many natural laws which man has never discovered, though we can see the results of their operation.

5. Energy. — This is a subject of great importance in physics, and should be studied carefully. As with matter, it is hard to say just what *energy* really is; but we may say for a definition: *Energy is the ability to produce motion.*

Matter cannot of itself cause motion; when any body of matter seems to cause motion in itself or in some other body, it does so by virtue of the energy which for the time it possesses. A body of matter may gain or lose energy without changing in size or weight, or in any other way that we should commonly notice. Energy must then be something quite different from matter, having no substance and occupying no room, yet very important because without it no motion would be possible.

6. Force. — When the energy of a body is used in an effort to cause motion, we generally say that *force* is exerted. Thus a moving body is said to "exert force" upon anything that it strikes. Similarly in the case of a bat acting upon a ball, a bowstring upon an arrow, a hanging body upon the support from which it is suspended, steam in an engine, or an exploding powder charge in a gun, — each is an example of some force acting. Notice that the effect of these forces is to cause motion or to make an effort to do so. A moving body gives motion to the body that it strikes, even if it is only the air; the ball, the arrow, and the bullet in the gun move when forces act upon them. But in some cases, as the hanging body or the steam in a boiler, the force may not be seen to cause motion; still the steam pushes hard upon the sides of the boiler, and the hanging body tries to pull its support downward. In these examples force is exerted; but because it is not great enough it may seem to cause no motion, and we say that it *tends* to produce motion.

From our study we shall become more familiar with the use of this word than any definition can make us, but for the sake of a definition we may say, *Force is the direct cause that tends to produce motion or a change of motion.*

7. Forms of Energy. — Like matter, energy occurs in many different forms. Naturally, too, we apply names to many different forces acting in the world. We shall learn more about these forms of energy and these forces as we study further.

QUESTIONS

1. What do you understand the term *science* to mean?

2. Why is scientific study divided into many branches? Name several of these branches. How are they related?

3. Define physics. What is included in the word *matter?* Name some forms of matter. Can you name anything which is not matter?

4. What is a natural law? How are natural laws discovered? Are there any that are not yet known? Can natural laws be broken?

5. Define energy. Define force. Carefully show the difference between them.

6. Give examples of bodies which have energy but exert no force. Give examples of forces tending to produce motion, without succeeding.

SECTION II

COMPOSITION OF MATTER

8. Three States of Matter. — Matter occurs in three states or conditions — as solids, liquids, and gases.

Solids are those bodies that keep the same size and shape unless changed by some outside force. Glass, wood,

iron, cloth, paper, wax, ice, leather, and rock are examples of solid substances.

Liquids keep the same size, but change their shape according to the vessel in which they are. Water is the most common liquid; others are alcohol, benzine, kerosene, ether, and mercury.

Gases do not keep either their size or shape, but expand without limit. For this reason a gas cannot be kept

FIG. 2

pure unless it is in a tightly closed vessel. If a bottle of some gas be uncorked and left so, in a few minutes the gas will escape into the air and the bottle will contain only a very little, mixed with a large amount of air. This is because the tiny particles of any gas are always in rapid motion, and so they become separated from each other, mixing with particles of other gases. This process is called *diffusion*. Gases are much lighter than liquids or solids. Most of them are invisible (cannot

be seen) and only a few have any color. Air is a gas, as is also steam, hydrogen, oxygen, chlorine, and others. Many gases which cannot be seen may be discovered by their odor; as coal gas, illuminating gas, ammonia, etc.

Vapor is a name given to such gases as easily change to liquids; as steam. True steam is invisible, the white cloud that we call steam being made of tiny drops of water. At the spout of a kettle we sometimes notice a seemingly vacant space (Fig. 2) where there is really steam; in a moment this steam has cooled into drops. Smoke is not a gas, but is a mass of solid particles.

9. Changes of State. — In general, substances change from solids to liquids and from liquids to gases upon being *heated.* For some kinds of matter great heat is necessary.

Experiment 2. — Gently heat small quantities of ice, wax, paraffin, sugar, or butter, and note the changes which take place.

Experiment 3.—Fit a stopper into a test tube, and through the stopper run a glass tube, as in Fig. 3. Into the test tube put a small quantity of water, alcohol, ether, or benzine. Dip the open end of the glass tube under water and gently heat the liquid in the test tube. Note carefully and explain all that you see. Be sure to apply only slow heat and use caution with volatile liquids.

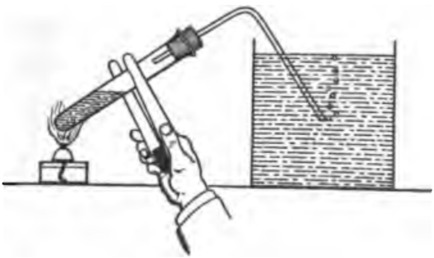

FIG. 3

In general, gases change to liquids and liquids to solids upon being *cooled.* Air and other gases are now changed to liquids, and some even to solids, by cooling to a very low degree. Steam is so commonly changed to liquid particles that we carelessly call the liquid "steam."

Experiment 4. — Boil some water in a test tube. Hold a cool dish in the steam just as it escapes from the tube. (A glass dish, if clean and dry, may best serve the purpose.) Explain what you observe.

Experiment 5. — Melt some paraffin, wax, or sugar, and let it cool rapidly. What change takes place? Under what condition does the change occur?

Most forms of matter occur commonly in only one state, because the temperatures at which they would change are unusually high or low. Some substances, however, are common in two states: ice, wax, sugar, and vaseline easily change to liquids; while such liquids as alcohol, ether, naphtha, and chloroform readily change to the gaseous state. Water commonly occurs in all three states; as ice (a solid), water (a liquid), and steam (a gas).

10. Composition of Matter; Molecules. — All matter is made up of tiny particles called molecules. A *molecule* is the smallest particle of any substance which can exist alone without changing its nature. From this definition it is clear that a molecule is too small to be seen; for the smallest bit of matter which could be seen would be capable of division into other bits much smaller. Still we know that there must finally be particles so small that they can no longer be divided; and although no one has ever seen them, we can give them a name — molecules.

11. Molecular Theory. — Now because these molecules are too small to be discovered, no one knows exactly how they are put together to form any body of matter. There are several like cases in scientific study, when things cannot be definitely known but are only explained by guess. Such guesses are not rash, however, or hasty; they are made by men who have studied and thought deeply, and may generally be taken as probably true explanations. An explanation of this sort is called a *theory*. The explanation of the composition of matter is called the molecular theory; while it cannot of course be proved by ordinary methods of proof, it is generally believed by scientists.

The *molecular theory* states that the molecules in any body are separated from each other by spaces called *pores*. These pores are larger than the molecules themselves, and in them the molecules are supposed to move rapidly to and fro. The rapid to-and-fro motion is called *vibration*.

Experiment 6. — The existence of pores may be shown by dipping a piece of gold (one of the densest of solids) into a cup of mercury (quicksilver). The molecules of mercury will fill the pores between the molecules of gold. (The mercury can be removed from the gold by dipping into nitric acid.) Similarly iron will take water into its pores.

QUESTIONS

1. Name the three states of matter. Define each. Give examples of each.

2. What features do most gases have in common? What is meant by diffusion? How is diffusion caused? What is a vapor? What is smoke?

3. How, in general, may the state of a substance be changed? Give any common examples of changes caused by heating; by cooling.

4. Can steam be seen? Why does steam always form a white cloud when set free in the air? Of what is that cloud composed?

5. Give examples of substances common in two states. Why are not all substances common in more than one state?

6. What is a molecule? What are pores?

7. State the molecular theory in your own words. What does it attempt to explain? Is it known to be true?

SECTION III

PROPERTIES OF MATTER

12. Common Properties. — The features which any form of matter possesses are called its *properties;* such, for example, as its color, density, hardness, and the like. As there are many different substances, there are also many different properties. Very few of these are possessed by all forms of matter, though several are common to many substances. We shall consider only a few of the more common properties.

13. Impenetrability. — This long word names a property which is common to all matter, — that of completely occupying the space in which it is. This fact is sometimes stated as follows: No two bodies can occupy the same space at the same time. No body of matter can enter a space already filled, without first driving out the substance which fills it. Notice that we say the *same space;* this does not mean that two things cannot be in the same dish, for example, since they can both be in a dish together without filling the same space.

Experiment 7. — Hold a bottle, mouth downward, over water and push it downward (Fig. 4). Compare the height of the water in the bottle with that around it outside. Give a reason for this difference. Now tip the bottle sidewise, as in Fig. 5, and note all that happens. What takes place now that did not occur when

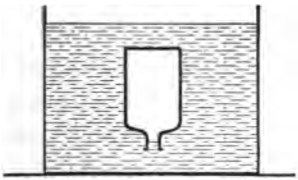

FIG. 4

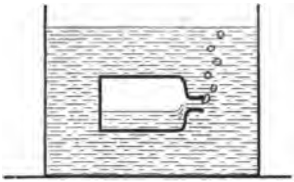

FIG. 5

the bottle was held in the other position? How do you explain the difference?

It is hard to fill a small-mouthed bottle with a thick liquid like oil or molasses, because of the bubbles of air which must escape as the liquid enters.

14. Cohesion. — *Cohesion is the force which holds the molecules of a body together.* This is a property common to solids and liquids; the molecules of gases, we have learned, do not *cohere*, and therefore are free to become widely separated. The greater the *cohesive force* between the molecules of a substance, the more the substance resists being broken or pulled apart. When cohesion is great, a body is said to be *tough.*

Experiment 8. — Try to break pieces of different substances, *e.g.* wood, glass, leather, bone, steel wire (knitting needles), iron wire, copper wire, etc. Make a list of these in the order of their cohesive force.

Experiment 9. — Hold a drop of water on a glass rod. Is there anything about this to show that the molecules of water cohere?

Broken solids cannot be mended by simply pushing the pieces together, because the molecules cannot be forced near enough to each other. Some substances, such as iron, may be heated until soft, however, and then the broken ends may be pounded until they unite. This process is called *welding*.

15. Adhesion.—*Adhesion is the force which holds the molecules of one body to those of another.* Only a few substances have this property, and even they will not *adhere* to many others. No paste, glue, or cement will stick to everything; each is made for certain substances.

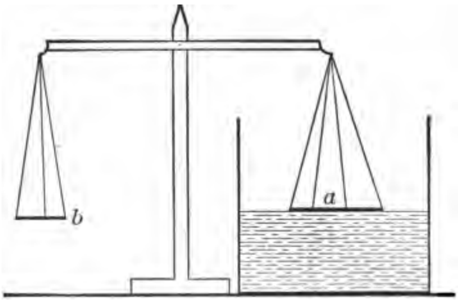

FIG. 6

Experiment 10. — Balance a piece of glass, *a* (Fig. 6), with weights on the pan *b*. Place a vessel beneath *a*, and pour water into the vessel till its surface just touches the piece of glass. Add more weights to the pan *b* until the glass *a* is lifted from the water. Why do you have to add more weights? How much more do you add? What force are you now measuring?

16. Hardness. — A *hard* substance is one in which the molecules resist any change of position. This property of course applies only to solids, for the particles of liquids and gases move about freely.

Experiment 11. — Using pieces of wood, glass, iron, copper, lead, soap, and quartz, try to scratch each with the others. Which scratches all of them, and which scratches none? Arrange them in a scale according to hardness.

Articles made of soft iron may be *hardened* by heating to a high degree and plunging at once into water or oil. Springs are tempered in this way, after being bent. Hardened iron may be made soft by heating and then slowly cooling; this is called *annealing*. Try each process.

17. Brittleness. — It may be noticed that certain substances, though they are hard, are easily broken by a blow. Glass, for example, is easily broken to bits by a blow from a hammer, by being dropped upon a hard surface, or sometimes by mere pressure of the hand. Some knife blades, though of very hard steel, may be snapped in the fingers. Such substances as are thus easily broken by a blow are said to be *brittle*.

Experiment 12. — Test the brittleness of various substances by hammering lightly, by dropping them upon a hard surface, or by trying to snap them in the fingers. Chalk, pasteboard, glass, iron wire, a steel needle, copper wire, a cracker, a bit of china, a watch spring, or a wafer may serve as examples.

18. Malleability. — A solid substance that may be hammered into thin sheets is said to be *malleable*. Several of the metals are very malleable and may be rolled into sheets thinner than tissue paper. Gold is the most malleable of substances; it can be hammered into sheets that are only $\frac{1}{300000}$ of an inch thick. We are familiar with thin sheets of this metal under the name "gold leaf."

Experiment 13. — Hammer some bits of different substances into the thinnest sheets you can make. Try lead, iron, tin, copper, aluminium, and others.

19. Ductility. — Some solid substances may be drawn out into small wires; they are said to be *ductile*. In several cases a ductile substance is also malleable, but this is not always true; a body whose malleability is great may have small ductility, and the reverse is also true. The ductility of platinum is very great, for it may be drawn into wires that are only $\frac{1}{6000}$ of an inch in diameter.

Experiment 14. — Heat a small glass tube in a flame, holding it at both ends. When the tube is well heated in the middle (*i.e.* red hot and soft), remove it from the flame and quickly draw the ends outward. Examine the portion that was heated.

20. Tenacity. — The property whereby a solid body resists being pulled in pieces is called *tenacity*. This property is similar to cohesion, though not so broad in its meaning. Steel wire has great tenacity, a very small wire being able to support a heavy mass.

Experiment 15. — Take a strip of fresh writing paper two inches wide. Fold so as to make it one inch wide and of double thickness. Grasp one end firmly, while some one else grasps the other end. Now both pull *steadily* till the paper breaks in two pieces. What do you conclude with regard to paper?

21. Porosity. — We have learned that all bodies of matter are composed of molecules and *pores* or spaces between molecules. The size of these pores varies greatly in different substances, but in any body they are much larger than the molecules. Even in dense masses, such as a piece of lead or silver, these pores are present, though the mass appears to have no such spaces and none can be seen through a microscope.

Some substances, though the spaces between their molecules cannot be seen, include in their structure many larger spaces that can be seen. Such substances are usually made of many fibers or cells loosely put together, and the spaces between these small parts are sometimes called pores also. A sponge or a piece of blotting paper clearly shows this structure. A body of this sort is generally said to be *porous.*

22. Compressibility. — Given a bundle of loose cotton, we know that it could be crowded into a much smaller bundle; but in such a case its fibers would be much nearer together. In a similar manner the molecules of some substances may be crowded nearer together, the pores becoming smaller and the whole body losing some of its size. The property whereby a body may thus be crowded into a smaller space is called *compressibility.* As a general rule, solids and liquids are not very compressible; great force is required to crowd their molecules nearer together. Gases, however, have great compressibility; their molecules under ordinary pressure are widely separated, and when great force is used they may be driven very much nearer together.

23. Elasticity. — *Elasticity is that property by which a body goes back to its former size and shape after the force which changed it has been removed.* It is very important to notice that a body is *elastic* not because it may be bent or stretched, but because it goes back to its former state as soon as the force ceases to act. Ivory is very elastic, as is glass; rubber is not so nearly

perfect in elasticity. Gases are very elastic and liquids as well. Substances like clay, putty, and butter are said to be inelastic.

Experiment 16. — Fill a football or bicycle tire with air under pressure. Push upon its surface with the hand, at once removing the hand. Is any dent left in the surface? Is air elastic?

Measure a coiled spring. Push it at both ends so as to shorten it; then let go and again measure the spring. Is it any shorter? Is it elastic?

24. Crystallization. — Many substances have the property of forming themselves into *crystals* upon changing from a liquid to a solid state. These crystals always have a definite shape, though in different substances the shapes may differ. Quartz crystals are commonly seen in rocks; also garnets. Diamonds, rubies, emeralds, and other gems are crystals of rock. Sugar is the crystallized juice of cane or beet, snowflakes are crystals of water, and many salts are crystals.

FIG. 7

Experiment 17. — Dissolve some alum or sugar in warm water until no more can be made to dissolve. Hang a string in the water (Fig. 7) and let it stand for a day. Examine it from time to time. State what you observe and try to explain it.

Experiment 18. — Melt some roll sulphur by heating and allow it to cool slowly. When hard, examine the mass and tell what you find. Compare the results of these last two experiments. Compare the methods used.

Some substances do not crystallize; these are called *amorphous* substances. Crystalline bodies may be recognized by their form, or sometimes by the shining surfaces that they show when in a mass together. Butter, glass, wood, flour, paper, coal, cloth, and wax are examples of amorphous substances.

25. Capillarity. — The adhesive force with which some liquids are attracted to certain solid substances causes a useful and interesting action called capillary action or *capillarity*.

Experiment 19. — Put water into a clean glass tumbler and carefully note the surface of the water where it meets the glass.

Now put a clean glass tube of very small bore down into the water vertically. (An old thermometer tube, open at both ends, may be used.) Note the height of water in the tube. What force holds it in that position?

Water has so great an adhesion for glass that small amounts of it may be raised by means of this force. The smaller the tube, the higher that small amount of water will rise in it. The oil rises through a lamp wick by capillarity, the wick being a woven mass of tiny fibers.

26. Inertia. — One property of matter which, though very passive, is of great importance is that of *inertia*. To state it briefly, inertia means the complete lack of any ability of matter to cause or to change motion. No body at rest can start itself moving; some force must be used, and then the body is started gradually. Also no moving body can stop itself or in any way change

its motion; again some force must be applied in some way.

This is one of the few properties that are common to all matter. It will be treated more fully in §§ 56, 59.

QUESTIONS

1. What is meant by the properties of matter? Name as many as you can. Are any properties common to all forms of matter?

2. What is meant by impenetrability? Name an example of its effect.

3. Define cohesion. Do the molecules of liquids cohere? Do those of gases? Explain how a blacksmith uses cohesion in welding iron.

4. Define adhesion. Name some substances that adhere to each other. Which have the greater adhesion generally, solids or liquids?

5. Upon what does hardness depend? How may iron be hardened? How may a body be annealed?

6. Name some substances that are brittle. How would you test the brittleness of a body? Are brittle substances ever hard?

7. What is meant by malleability? Would you expect a brittle substance to be also malleable? Name some bodies of matter that you think are malleable.

8. Name some substances that you know to be ductile. How do you know that they have this property? Is a malleable body necessarily ductile?

9. How would you test the tenacity of a body?

10. What is commonly meant by a porous body? What sorts of bodies are porous?

11. What class of substances is most compressible? Explain why bodies of matter may be thus compressed.

12. Define elasticity. Is air elastic? Is water elastic? Name some common uses of elasticity.

13. Under what conditions may crystals be formed? Name some substances that crystallize. Name some substances that do not form crystals. What are such substances called?

14. Explain the cause of capillary action. Name some important use that is made of capillarity.

15. Name the property shown by the substance in each of the following cases: a watch spring in unwinding; a blotting paper in absorbing ink; a stick when it is not easily broken; a bit of steel that can scratch glass; the air forced into a bicycle tire; vapor in the air when it forms into snowflakes; a wire when it supports a heavy weight.

SECTION IV

PROPERTIES OF MATTER: GRAVITATION

27. Gravitation. — We already know three facts: that bodies near the earth fall towards it if they are free to fall; that all bodies on the earth are held down by some means which we cannot see; and that the earth, moon, and planets are held in place also by some invisible means. It is clear that there must be some great force doing these things, and we call this force *gravitation*.

28. Gravity. — Not only do these things occur, but scientists tell us that every body of matter has the power of attracting every other body — not only solids but liquids and gases as well. The only reason that they do not succeed in drawing together is that the earth draws each body more strongly, thus holding each in place. The force exerted by the earth in attracting and holding bodies is just the same as the common force exerted by all matter, that is, gravitation; but

for convenience it is called *gravity* when spoken of in connection with the earth.

It is hard to realize the importance of gravity and the part that it plays in our daily lives. Without this force nothing would stay on earth if it were once moved upward; a ball thrown into the air would never return; a locomotive would have no weight upon the rails; and we could not even walk.

29. Law of Gravitation. — Care must be taken to avoid thinking of gravitation as magnetic force. The two are very different; for while magnetism is shown in only a few substances, gravitation is a common property of all forms of matter equally. One form of matter can exert as much of this force as another form, and the amount which any body can exert depends only upon the quantity of matter that it contains. It is because the earth contains so much matter that the *force of gravity* is so strong.

When two bodies attract each other, the strength of the force depends upon two things — the *quantity of matter* in them and the *distance* between their centers. The greater the amount of matter, the more they attract each other; the greater the distance, the less they attract. These two facts taken together make up the *Law of Gravitation.*

30. Weight. — Keeping this law in mind, a little thought will show us that the force with which two bodies *at the same place* will be drawn towards the earth depends only upon the quantities of matter in them. That is, the more matter a body contains, the stronger

will be the action of gravity upon it. Thus by measuring the force with which gravity pulls a body we can judge of the amount of matter in it.

The *weight* of any body is the measure of the force with which gravity pulls it. This may be found by holding the body suspended by some known force. Fig. 8 shows a common spring balance; anything hung upon the hook will be pulled downward until the stretched spring exerts as much force upon it as does gravity; there it will stop, and the pointer will show this force in pounds or ounces, etc.

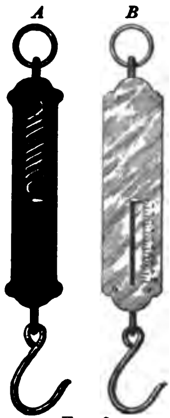

FIG. 8

31. Specific Gravity. — Of two pieces of lead, the larger weighs more; but a piece of lead may weigh more than a much larger piece of wood. That is, some forms of matter are naturally heavier than others. In order to compare the weights of different forms of matter, we must weigh *equal amounts of volume* (size) of the different substances. To express these comparisons easily, the weight of each substance is referred to that of *water* as a standard. For example, a piece of iron is found to weigh seven times as much as an equal volume of water, a piece of lead eleven times as much, a piece of gold nineteen times as much, and so on. A list is then made, each substance being named and followed by the number showing how many times the substance is heavier than water, and the number is called the *specific gravity* of the substance.

Specific gravity is the weight of a substance compared with the weight of an equal volume of water. The specific gravity of water is 1; of cork, 0.2; of ice, 0.9; of iron, 7.2; of lead, 11.4; of mercury, 13.6; of gold, 19.4; of glass, 3.4; and of platinum, 21.2.

QUESTIONS

1. Name some examples of the effect of gravitation.

2. What is meant by gravity? Is it any different from gravitation?

3. Name some effects of gravity. If there were no such force, would bodies fall to the ground? Why could we not walk if there were no such force?

4. Upon what two things does the strength of gravitation depend? Would the moon attract a body more or less than the earth, — that is, would a body weigh more on the moon or on the earth? If we were on the moon, could we jump higher than we can on earth?

5. Define weight. Explain how weight gives us an idea of the amount of matter in a body.

6. What is specific gravity? Does it depend upon the kind of matter or upon the size of the body? Would a lump of gold weigh more or less than the same volume of lead?

CHAPTER II

FLUID PRESSURE

SECTION I

PRESSURE IN LIQUIDS

32. Fluids. — Liquids and gases are called *fluids* because they will flow. This property of liquids and gases is due to the fact that *their molecules move freely among each other* from place to place. The molecules of a solid, of course, vibrate, each in its position (§ 11), but none of them can easily change its position among the others; hence a solid body preserves its shape. The molecules of fluids, on the other hand, change their position so easily that the simple force of *gravity* is enough to move them, *pulling each downward as far as it will go.*

Experiment 20. — Pour a tumbler of water into a large flat dish; it spreads out to the edges of the dish. Pour it upon a larger surface (a board or piece of glass) and note what happens. How may this be explained? What force acts upon the liquid? Is its action strongly resisted?

Thus we learn why it is that liquids flow downward. Gravity acts in the same way upon the molecules of solid bodies also, pulling each of them downward; but in them the force which holds each molecule in its place among the others is greater than the force of gravity upon it, so that it does not move. In liquids and gases the molecules are free to move as gravity pulls them.

33. Cause of Pressure in Liquids. — If a liquid flow or be poured downward until it is stopped, gravity still acts upon it and causes it to push upon whatever stops it. Thus when the flow of a liquid is stopped by the bottom and sides of a dish, a pond, or even the ocean, the liquid exerts force upon those sides and the bottom. Each particle is still acted upon by gravity, and in an effort to go lower *it exerts force upon the particles around it in all directions.* For this reason water will spurt from a leaky hose equally in any direction. This principle may be stated as follows: *At the same depth in a liquid, pressure is equal in all directions.*

FIG. 9

Experiment 21. — Cover the end of a lamp chimney with cardboard and push it into water in a glass dish (Fig. 9). Pour water into the chimney till it reaches the same level as the water outside. Add a bit more water and watch the result. Explain what you see.

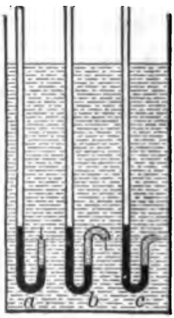

FIG. 10

Experiment 22. — Bend three tubes, as *a*, *b*, and *c* (Fig. 10), so that the ends may open upward, downward, and sidewise. Put equal quantities of mercury into each, so that it may stand at the same level in all. Now lower the tubes into water till

the openings are all at the same depth. The mercury is thus forced up into the long arm of each tube (which must reach above water) by the force of the water at the end. Compare the height of the three mercury columns. What does this show regarding liquid pressure at a given depth?

34. Pressure depends upon Depth. — Now, since pressure in liquids is caused by the action of gravity upon their molecules, and gravity acts downward only, it is clear that the pressure upon any point will depend only upon the weight of the molecules *above* it. It is also clear that the weight will depend upon the number of particles above the point, and that their number will in turn depend upon the *depth* of that point below the surface. From this we may state the general principle: *In any liquid, pressure upon a point increases with its depth below the surface.*

Experiment 23. — Push an empty can into water slowly, taking care not to get it entirely below the surface. Do you notice any difference in the force that you have to exert as the can goes farther down?

35. Surface Level. — Since gravity pulls all particles of a liquid as low as possible, and the particles are all free to move, no part of a liquid surface can be higher than another unless acted upon by some force that is stronger than gravity; that is, *the surface of a liquid at rest is always level.*

36. Water Supply. — If a vessel *a* (Fig. 11) be filled with water to a height *cc′* and then connected with an empty vessel *b* by a tube at the bottom, the water will flow out of *a* and rise in *b* until it stands at the same

level in both vessels. *Gravity* makes the liquid flow from *a* and causes *liquid pressure* which is great enough to force it upward into *b*. In the same way these forces are used to give cities a supply of water.

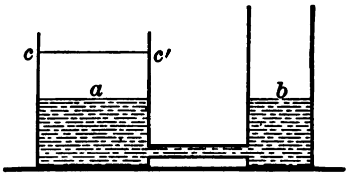

FIG. 11

Pipes from a pond or *reservoir*, located on high land, lead the water down into the city. Gravity of course causes it to flow downward, giving it pressure enough to fill the pipes. In these pipes the water may rise to the tops of buildings, provided they are not as high as the surface in the reservoir (see Fig. 12). These pipes may be tapped at any points by faucets, hydrants, or fountains, out of which the water will run with some force. The force with which the water runs is called its *head;* the head of water at any point generally increases with the vertical distance from the point to the surface in the reservoir,

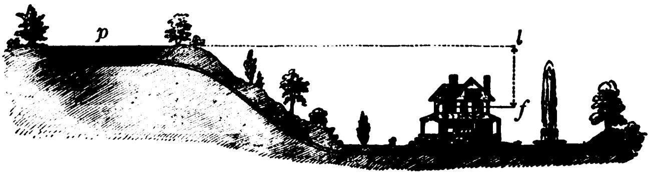

FIG. 12

as *lf* (Fig. 12). Some force is used up by the rubbing of the water on the pipes as it flows, so that its head is less as the distance away from the source increases.

37. Buoyancy. — We have doubtless noticed that many bodies seem to weigh less when held in water.

In lifting an anchor or a stone from under water, it seems to be heavier the moment it rises above the surface. It may be said, in general, that all bodies *seem* to weigh less when held in a liquid. This is not because the thing really does weigh less, but because it is then acted upon by some other force which acts in the opposite direction to the force of gravity. The force is exerted by the liquid body and is called *buoyant force.*

Experiment 24. — Hang several heavy bodies (*e.g.* a stone or a scrap of iron), one at a time, to a sensitive spring balance. Note the weight of each. Then, without removing it from the balance, lower each over water till it dips wholly below the surface, and again note its weight. Does it pull the pointer down more or less when in the water? How do you account for this? Does each body really change in weight or only seem to? Can you measure the buoyant force in each case?

38. Buoyant Force explained.—The molecules of any liquid at rest will, of course, be as low as gravity can pull them. If, now, any body be lowered into that liquid, some of the particles will be *displaced* (pushed out of their places) and the surface of the liquid will be raised by an amount just equal in volume to the size of the body which displaced it. These particles will, of course, be still pulled downward by gravity, and in tending to return to their places they will exert force upon the body. Since this force will cause greater pressure upon the bottom (see § 34), the body will, of course, be pushed upward.

It is clear that any body held entirely in a liquid will displace its own *volume* (size) of the liquid. And as the body is buoyed upward by the force that these displaced

particles exert, it follows that the force tending to hold it up is equal to the weight of the displaced liquid. In other words, *any body held in a liquid is buoyed up by a force equal to the weight of the liquid displaced.*

Experiment 25. — Fill a vessel *a* (Fig. 13) with water, so that no more can be added. Weigh some heavy body in air and again while dipped in the water, as in Fig. 13. Note the loss of weight.

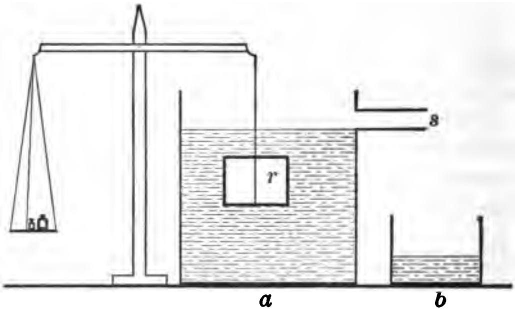

FIG. 13

Arrange a vessel *b* so as to catch the water which spills from *a* as *r* is lowered into it. Weigh the water caught, comparing with the loss of weight just found.

39. Floating Bodies. — The specific gravity (see § 31) of many substances is less than that of water; such bodies *float* upon its surface. If any body floats upon a liquid surface, neither rising nor falling, it is clear that its weight is just *balanced* by the buoyant force acting upon it. But we have learned that buoyant force is always equal to the weight of liquid displaced. From these two facts we can easily form the *Law of Floating Bodies: Floating bodies displace an amount of liquid equal to their own weight.*

Experiment 26. — Using blocks of different sorts of wood, of cork, ice, Ivory soap, etc., float each upon water. In each case compare the amount above the surface with that below. Try to float iron, copper, lead, or rock upon mercury.

Many heavy substances may be so shaped as to hold a great amount of air, and then they may float. Many vessels are now made of iron or steel; they float because they contain so much space filled with air that the vessel *as a whole* is lighter than the same volume of water.

40. Specific Gravity of Liquids. — Like solid substances, liquids vary much in the kind of matter of which they are made, and therefore they differ in weight. Hence it is desirable to know the specific gravities of liquids as well as solids. In this case, also, *water* is used as the standard, the weight of the various liquid substances being compared with that of an equal volume of water. To avoid weighing the liquid a simple device is commonly used, called an *hydrometer*. An hydrometer is a hollow tube of glass weighted at one end and having a scale of specific gravities marked on its stem (Fig. 14). Upon being put into a liquid it sinks more or less, according as the substance is light or heavy, and the mark on the scale where the liquid surface rests will show the specific gravity of that substance.

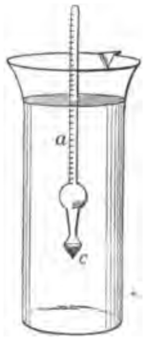

FIG. 14

Experiment 27. — Shake some oil and water together in a test tube. Let it stand some minutes; examine and explain.

Put a drop of mercury into a glass of water. What happens?

41. Hydraulic Press.— The use of liquid bodies to *transmit* pressure is common and important. The principle may be stated as follows: If a body of liquid be entirely closed up in any vessel, and any part of its surface be put under pressure from without, that pressure will be felt just as greatly upon *every equal part* of the inside surface of the closed vessel. For example, the inside surface of a bottle is fifty square inches and the lower surface of its stopper is one square inch; if the bottle is full of water, the stopper fits tightly, and a force of two pounds pushes the stopper down upon the water, and every one of the fifty square inches of inside surface in the bottle feels a pressure of two pounds upon it. The pressure on the whole inside surface of the bottle is $(50 \times 2) = 100$ pounds.

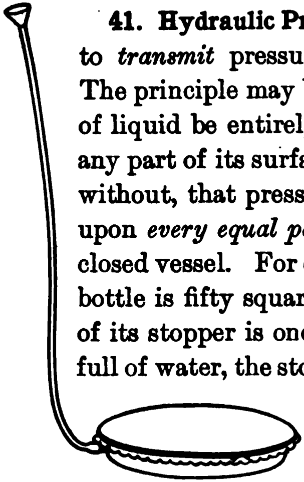

FIG. 15

Experiment 28. — Get a shallow circular pan, make a small hole in its side, and solder into this a short metal tube (Fig. 15). To this tube attach a rubber tube two or more feet long. Tie a piece of sheet rubber very firmly over the top of the pan. Fill the whole with water, keeping the tube full. Raise the tube as high as possible. See how great a weight

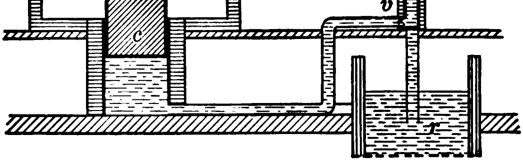

FIG. 16

of books you can raise up from the rim of the pan. To what is the pressure due?

Fig. 16 shows how this principle is used in the *hydraulic press*. The piston *p* is small and the cylinder *c* is many times larger; if *p* is pushed downward, water in the pipe transmits its pressure to the lower end of *c*, and *c* is pushed upward with as much greater force than is used at *p* as the lower surface of *c* is greater than that of *p*. Very powerful presses and *hydraulic jacks* are made in this manner.

QUESTIONS

1. What substances are called fluids? Why? What force causes fluids to flow? Does the same force act upon the particles of solid bodies? Why do they not flow?

2. Explain how pressure in liquids is caused. At the same depth in a liquid what is true of pressures in different directions?

3. Upon what does the greatness of liquid pressure depend? State the law or principle in regard to this.

4. What is true of the surface of a liquid at rest? Explain why this is so. Did you ever see a liquid surface which was not level? What made it so? Was it at rest?

5. Explain the method of supplying cities with water. Could the reservoir be lower than the city? How high will water rise in the pipes? Why does it not rise as high as the surface in the reservoir?

6. Show the cause of buoyancy in liquids. Does it act upon all bodies, heavy and light? State anything of this sort that you have experienced.

7. Give the general law for buoyant force. State the Law of Floating Bodies. Why do steel vessels float?

8. How is the specific gravity of a liquid most easily found? Cream is made of oily particles. Why does it rise to the top of milk? Why does it not rise more rapidly?

SECTION II

ATMOSPHERIC PRESSURE

42. Cause of Atmospheric Pressure. — The *atmosphere* is a mixture of gases, commonly called air. It is known to extend many miles above us (probably over one hundred), though the greater part of it is within five or six miles of the earth's surface. Now we have found that air is matter, for it occupies space (§ 3), and we know that all matter is acted upon by gravity; therefore we see that *the atmosphere must have weight.*

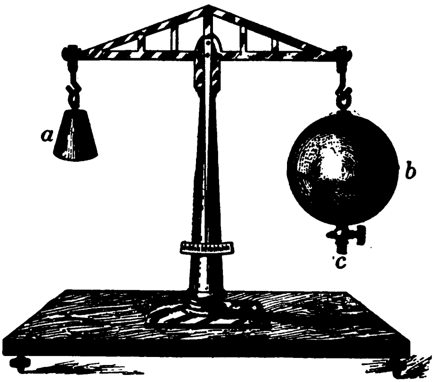

FIG. 17

Experiment 29. — If possible, secure some vessel from which the air may be removed and kept out — like the globe in Fig. 17. Remove the air by using an air pump, and close the stopcock *c*. Balance the globe with weights on the scale beam at *a*. Then open the stopcock, letting air into the globe *b* again. Is the globe now balanced by the weights at *a*? How do you account for this? Add weights until both sides balance each other. What do the added weights represent?

If the air has weight, then, however little it may be, the total amount above us is so great that it causes a considerable pressure at the surface of the earth. So we see that atmospheric pressure is produced in just the

same way as pressure in liquids, — by the simple action of gravity upon its particles, — and like liquid pressure, *it is felt equally in all directions*, — upward, downward, and sidewise.

43. Greatness of Atmospheric Pressure. — The pressure of the air upon objects at the level of the sea is about *fifteen pounds on every square inch of surface.* On mountains there is, of course, less air above the surface and the pressure is less; the difference is easily noticed.

This pressure seems very great for the simple weight of air, but we must remember that it reaches far above the earth — many miles. Water affords that amount of pressure at a depth of only thirty-three feet, and mercury at thirty inches.

We do not notice this weight of air because we have always lived under it; moreover, it does not crush us because it is equal on all sides of us, even entering the body in the lungs.

44. The Vacuum. — No body is crushed by atmospheric pressure for the reason just given (§ 43); that is, *it is felt evenly on all sides* — and inside as well as out. In a bottle, for example, the pressure of air inside is just the same as that outside; but remove the air entirely from the bottle, and we have then an unequal condition, — no pressure inside to balance fifteen pounds on every square inch outside. Clearly a weak bottle might be crushed by that weight.

Experiment 30. — Draw some of the air from a small bottle by suction, closing its mouth with your tongue. Describe all

that you observe. Try to pull the bottle off the tongue. Try to find an explanation for these things.

Experiment 31. — Blow into a paper bag until it is well filled out; then, without crushing it, open the end a little way so that the air inside may be under equal pressure with that outside. Now putting it to the lips, draw out some of the air and note what happens to the paper bag. Explain.

In these cases the air was partly removed. A space containing no air or other matter is called a *vacuum*. A space from which the air has been partly removed is called a *partial vacuum;* the air remaining in it is said to be *rarefied*. In practice, no perfect vacuum can be produced, but air has been rarefied to one-millionth of its usual density.

45. Some Effects of Atmospheric Pressure. — To understand the effects of atmospheric pressure, it must be kept in mind that whenever a partial vacuum is formed in any space, the pressure within the space is less than that of the air around it; also that the atmosphere, being a fluid, exerts force equally in every direction and can push itself into any opening, whatever its shape or size. In other words, *wherever a partial vacuum exists, the atmosphere tends to enter or to force something else in.* The effort of air to do this is seen in many common happenings, some of them useful and some annoying.

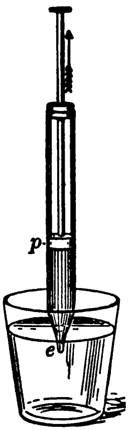

FIG. 18

Experiment 32. — Dip the end of a clean straw or other tube into clean water. With the other end at the lips, draw the air from the straw. What condition do you tend to cause within the tube? Do you succeed in causing that condition? Why? Describe and explain all that you observe.

Fig. 18 shows this same principle applied, though in this case the vacuum is formed in the tube by raising the piston *p*. Explain this.

Experiment 33. — Fill a small-mouthed bottle with water. When full, pour out the water and note that it comes in spurts. Explain. Now do the same with a baking-powder can. Does the water run out in spurts? Explain the difference.

FIG. 19

In pouring any liquid from a vessel through a small opening, a small amount will run out; this causes a partial vacuum within the vessel, into which the air forces itself and checks the flow of liquid while passing through the opening. The spurting flow thus caused is more marked in thicker liquids, like molasses and oil. To get a steady flow, an opening or vent is sometimes made in the vessel above the liquid surface; through this the air may run constantly, as the liquid runs out in an even stream below.

Experiment 34. — Fill a tumbler with water and cover it with a piece of stiff paper. Holding the paper in place, quickly invert the tumbler and hold it as in Fig. 19. Why does not the water run out? Pull down one corner of the paper, still holding the tumbler inverted. What difference do you note? How do you account for this?

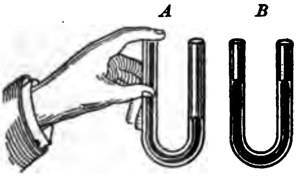

FIG. 20

Experiment 35.—Into a U-shaped tube pour mercury, as in *B* (Fig. 20). Now tip the tube till the mercury comes to one end, and cover that end with the finger. Keeping the finger tightly over the end, return the tube to the position in *A*. Explain what you observe.

Many other simple experiments may be performed, especially if an air pump is used.

46. The Barometer. — The *barometer* is a device for measuring the pressure of the atmosphere. This may be done by allowing the atmosphere to hold up as high a column of mercury as it will, and then weighing the mercury. If the column had a cross section of just one square inch, its weight would show us, in pounds, the pressure of the air upon one square inch.

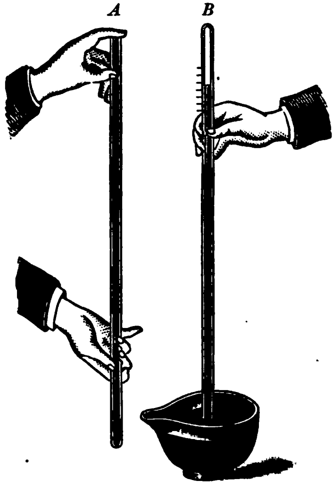

FIG. 21

Experiment 36. — To make a barometer, take a glass tube about 32 inches long, closed at one end; fill this with mercury, closing the open end with the finger, as in *A* (Fig. 21). Invert it into a cup of mercury, as in *B*, being careful to keep the end tightly closed until it is under the surface. Now remove the finger; a little mercury runs out into the cup, leaving a column about 30 inches long which is held up by atmospheric pressure on its lower end.

Since the tube was full and the mercury in falling from the top allowed no air to enter, it is clear that a vacuum is formed in the tube above the liquid. Thus there is no pressure on its upper end, so that the column is as high as the atmospheric pressure can force it.

As the air varies in weight from day to day it pushes the column higher or lower. Therefore *the higher the column of mercury, the heavier the air.* Changes in atmospheric pressure often attend *weather changes*, so that a change of weather may sometimes be foretold by

those who use the barometer. The measure of atmospheric pressure is commonly expressed by the height (in inches) of the mercury column.

47. Lifting Pump. — Water, being much lighter than mercury, can be held to a height of over thirty feet by atmospheric pressure. Clearly, then, water may be raised from a well thirty feet deep by the force of the air, if

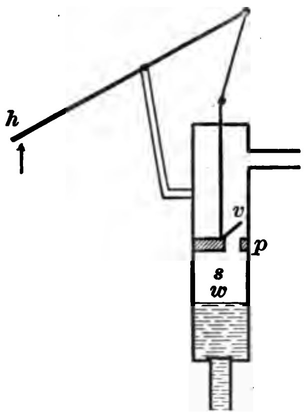

FIG. 22

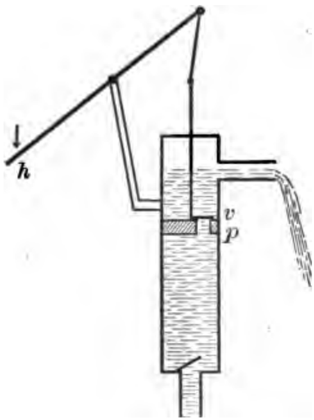

FIG. 23

we can only arrange to cause a vacuum in the upper end of the pipe. The work of a common pump, then, is to cause a vacuum in a pipe and to allow the water to run out above it. Figs. 22 and 23 will help to explain how this is done.

Fig. 22 shows the *downstroke* of a *piston p* moving in a *pump barrel.* A *valve v* swings freely on a hinge. As the piston moves down, air in the space *s* pushes the valve open and escapes above it. If now the piston is

raised (by pushing down the handle *h*), air pushing upon *v* from above closes the valve; thus no air can get into *s* and *a vacuum is formed there.* To fill this vacuum, atmospheric pressure upon the water in the well pushes it into the pipe. A few strokes of the piston removes the air entirely from pipe and pump, bringing the water up to the piston, as in Fig. 23.

Fig. 23 shows the piston on its *upstroke.* The valve *v* is closed by the water above it, which is lifted to the spout by lowering the handle. The space below *p* tends to become a vacuum, but is kept full of water by atmospheric pressure in the well, as explained.

48. Force Pump. — The lifting pump can raise water only as high as the air can hold it. To send it on to any distance, force has to be exerted upon the water by the pump. A device for doing this is called a *force pump;* a diagram is shown (Fig. 24) to explain its operation.

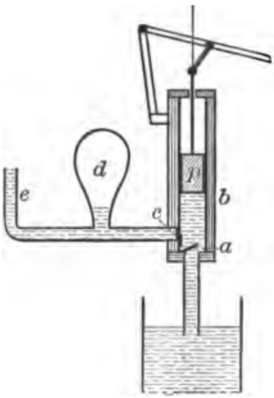

FIG. 24

In Fig. 24, *p* is a solid piston called a *plunger;* it has no valve. A valve *a* opens into, and a valve *c* out from, the barrel *b*. As the plunger is raised, *a* opens, letting water into *b*. Now when *p* is pushed downward, force is exerted upon the water in *b*, which causes *a* to close and *c* to open. Thus the water is sent to the pipe *e* under whatever pressure is given it by the plunger.

A *dome* *d* contains air. At each downstroke of *p* water forced into *e* rises a little way into *d*. The air in *d*, being elastic, drives out the water during an up-stroke of *p*, and this keeps up a more even flow in the pipe *e*. The dome is not strictly needed, but is generally used on force pumps to make the stream steady.

Water may be forced any distance if the pump is strong enough to do it, though great force may have to be used. Windmills and hot-air engines are commonly used to fill small tanks, while city water-supply systems make use of enormous pumps run by steam. Fire engines are only steam force pumps.

49. Siphon. — A *siphon* is a bent tube used for lifting fluids quietly from one vessel to another. It makes use of two forces — *gravity* and *atmospheric pressure.*

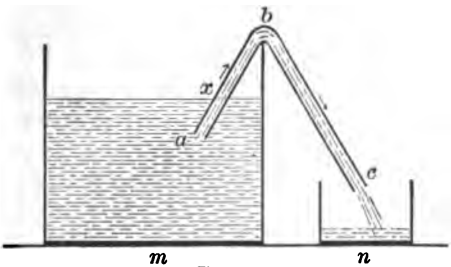

FIG. 25

Fig. 25 shows a simple siphon. The bent tube *abc* is filled with liquid from the vessel *m*, and allowed to hang so that the end *c* is lower than the surface of the water (x) in *m*. In this position gravity acts upon the liquid in both arms of the tube, but more strongly upon *bc* than *bx* because *c* is lower than x; thus the water will run downward out of *bc*. This tends to cause a vacuum in the tube at *b*, and atmospheric pressure forces water up *ab* to fill this vacuum. Of

course this keeps the tube full, and the water will continue to run as long as the vertical distance *bc* is greater than that from *b* to *x*.

Experiment 37. — Dip a long rubber tube into water until it is full. Pinch the end of the tube tightly to close it; draw this end out of the water, letting it hang over the side of the vessel. When the end is lower than the liquid surface in the vessel let it go, placing a dish to catch the water which runs. Now pinch the tube somewhere along its length, and again remove the pressure; the stream ceases when the tube is pinched. Does it flow again when the pressure is removed? How can you stop the flow entirely?

Siphons are convenient in getting liquids from barrels or other vessels from which they cannot be easily poured.

QUESTIONS

1. What is the atmosphere? Is it matter? Why does it exert force upon objects on earth? In what directions is that force felt?

2. How great is atmospheric pressure? Why do we not feel the weight of it? Why are not some bodies crushed by it? Is this pressure greater or less upon high land? Why?

3. What is a vacuum? What is a partial vacuum? What is the condition of the air in a partial vacuum? Name some examples of vacua which you have observed.

4. How does the atmosphere behave toward a vacuum? State any familiar examples of this. Why does a liquid run from a jug in spurts? Why does it not run in the same way from a pitcher?

5. What is a barometer? How is it made? Would a tube serve the purpose if open at its upper end? Why? How do barometer changes indicate changes of weather?

6. Explain how atmospheric pressure is used in raising water from wells. How high may water be raised by atmospheric pressure?

7. What is the use of a lifting pump? Explain its action. How does a force pump differ from a lifting pump in its action? Of what different use is it? Explain the use of the dome.

8. Explain the action of the siphon. What forces are used by it? How is the flow stopped?

9. Would a lifting pump serve its purpose if the piston did not fit tightly in the pipe? Why?

SECTION III

PRESSURE IN GASES

50. Expansion of Gases. — Gases differ from liquids and solids in that their molecules are not kept near together by cohesive force (§ 14). Therefore, since their molecules are always in rapid motion, there is no force exerted by the gaseous particles to prevent their becoming widely separated. Thus if a bottle of some gas be left open in a room, its molecules soon mix with the air and move to all parts of the room. Open the bottle of gas in a large vacuum, and the same thing happens; the molecules do not increase in size, but the spaces between them increase greatly. This increase in the volume of a gaseous body by the wider separation of its molecules is called *expansion.*

Gases therefore may be said to tend always to *expand;* and as their molecules exert no cohesive force to oppose this expansion, a gas can be kept in a certain space only by inclosing it completely within walls that may supply the necessary force. If a vessel is filled with a gas under ordinary pressure of the air, the gas is said to be under a pressure of *one atmosphere.* If,

now, this same body of gas expands so that its molecules are farther apart, it is said to be *rarefied.*

Experiment 38.— If an air pump can be had, any experiments like the following will serve to explain the point. Into the soft bladder of a football allow a small amount of air to enter — not enough to fill the ball, by any means. Close the opening tightly and, putting it under the receiver of an air pump, remove the air from around it. Watch the football closely while this is being done. What change occurs in the air within the ball? How is this change made possible? When you can remove no more air, note the appearance of the ball and admit the air again to the receiver. Explain what now occurs.

51. The Air Pump. — A device for rarefying gases is called an *air pump.* Fig. 26 shows a common sort. Its action is similar to that of the lifting pump, except that the air is sent from the *receiver* *r* to the pump barrel *c* by *its own expansive force.* As each stroke of the piston *p* removes some air, the expansive force of that which remains grows less and less until it is no longer strong enough to open the valves *a* and *c*. No more air can then be removed, and the vacuum in *r* will not be perfect.

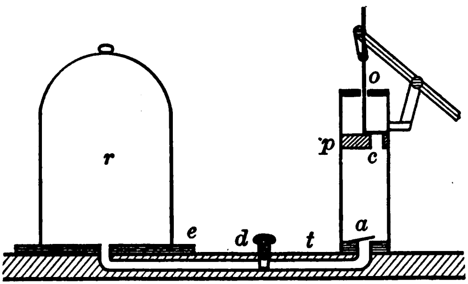

Fig. 26

A newer form, the *mercury air pump*, has no valves to be moved by the gas, so that the vacuum formed

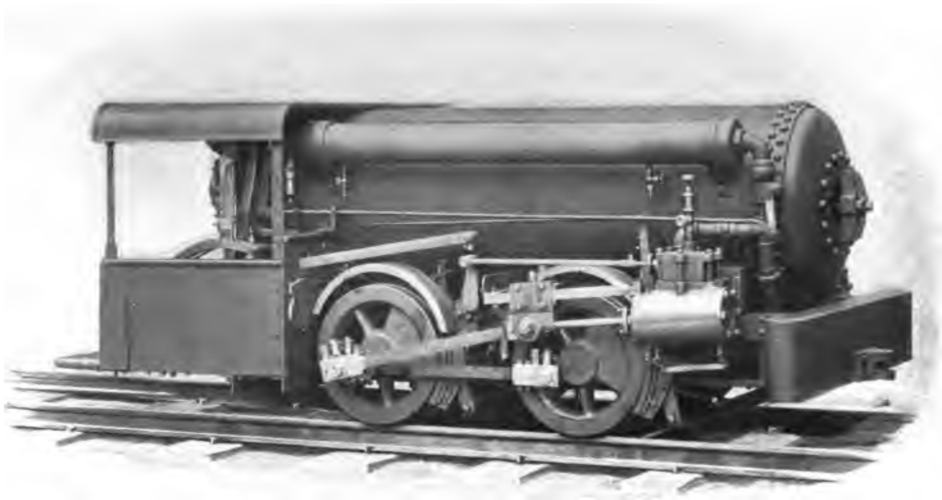

Plate II. A Compressed-Air Locomotive

may be more nearly perfect. With this pump gases may be rarefied to one-millionth of one atmosphere (§ 50).

52. Compression. — When a force greater than the pressure of the atmosphere is exerted upon any body *its molecules may be crowded nearer together;* the substance is then said to be *compressed.* In general, solids bear almost no compression, and liquids only a little; but *gases*, whose molecules are commonly far apart, may be compressed into a small fraction of their usual volume.

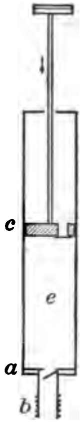

FIG. 27

53. Compressed Air. — We have learned that gases are elastic (§ 23); moreover, they are *perfectly elastic.* That is, when force has been used to compress a gas, *the gas will exert the same amount of force in trying to return to its former volume.* It is owing to this fact that *compressed air* is so much used as a motive force. Energy may be stored by forcing air into strong tanks under heavy pressure; the tanks are then carried about, and work may be done by the force which the air exerts when it is allowed to escape. Compressed-air engines are run by this means.

Experiment 39. — Fill a bicycle tire with air by means of a cycle pump (Fig. 27). Does it become harder to work the pump as the tire becomes filled? Why? Press upon the tire from time to time with the finger. Does it become harder to dent the tire? Is the tire more strongly elastic when well filled?

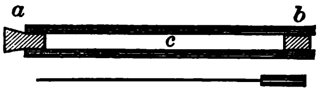

FIG. 28

Do the same things with a rubber football.

Experiment 40. — Make a common popgun, using a piece of elder (removing the pith) and two good cork stoppers. Fit the stoppers as in Fig. 28, and push upon the one at *b* until *a* flies out. Explain. How much air is in *c* (Fig. 29) as compared with *c* (Fig. 28)? What is its condition in *c* (Fig. 29)?

FIG. 29

54. Buoyancy in Gases. — Gases, like solids and liquids, vary much in specific gravity. If it were not for their tendency to diffuse, all heavy gases would sink to the ground and all that are lighter than air would rise. In a general way, gases do this, but of course they soon diffuse and lose their purity. If a gas can, however, be kept in a very light covering (*e.g.* a soap bubble), it will rise or fall in the air, according as it is lighter or heavier than air. Thus large amounts of *hydrogen* gas (only $\frac{1}{15}$ as heavy as air) may be put into a silk covering, and the whole will be so much lighter than the air that it will rise. In this way *balloons* are made. When large enough they may carry up heavy loads; but since the air becomes rarer as we go up from the earth, there is a limit to the height that a balloon may reach.

QUESTIONS

1. What shape does a liquid body assume when left to itself? (Think of liquids that are freely falling.) What becomes of a gas when left free in space? Explain the difference.

2. What is meant by expansion? Give examples.

3. What is meant by a pressure of one atmosphere? What is a rarefied gas?

4. What is an air pump? Explain its action. By what force is the gas removed from the receiver? Can it be entirely removed? Why?

5. When a substance is compressed what happens to its molecules? What sort of matter can bear most compression? Why?

6. Explain why compressed gases exert force. Name any uses of compressed air that you know of. Is a hollow rubber ball more elastic with or without a hole punched through it? Why?

7. Why do balloons rise into the air? How does the weight of a balloon compare with that of the volume of air that it displaces?

8. Why cannot a balloon rise to unlimited altitudes? Which could rise higher, a balloon filled with hydrogen or another filled with hot air? Why?

9. Explain the use of compressed air in a bicycle tire.

CHAPTER III

MOTION AND FORCE

SECTION I

NEWTON'S THREE LAWS OF MOTION

55. Newton's Laws. — Three *Laws of Motion* are named from Sir Isaac Newton, an English philosopher who was the first to state them. At first thought they may seem strange; and for this reason, as well as their great importance, they should be studied carefully and committed to memory.

First Law: *A body at rest will stay at rest, and a body in motion will keep moving in a straight line with the same speed, unless acted upon by some force.*

Second Law: *A change of motion follows the direction of the force which causes it, and is proportional to the amount of force used and the time during which it acts.*

Third Law: *To every action there is an equal reaction in the opposite direction.*

56. The First Law. — No doubt we can at once call to mind several cases which seem to prove this law untrue — but think a moment. Do any bodies really begin to move from a state of rest without the action of some force upon them? Can any moving body actually stop of itself?

You may say that a body will fall to the ground all of itself; but would it fall if the force of gravity did

not act? Will an engine begin to run without water in its boiler and heat under it; or an electric motor without its current of electricity? Can even an animal move itself without the energy supplied by food and air? In every case we should find that, if we knew enough about it, we could trace any motion to some outside cause.

Nor is it any easier to find a moving body which stops without force being used. Many bodies may seem to do so; but is it not, after all, the force of gravity which stops a rolling ball, a bullet, or other such moving body? Unfortunately we cannot, upon earth, find examples of constant motion without the action of force, because all motion (except downward) will be stopped by gravity if not by other forces; but doubtless many stars and planets are in constant motion simply because there is no force to stop them.

After all, this law merely states that *no body of itself can alter its state of rest or motion*, and that is not very odd. It would be far more strange if things *could* start or stop their own motion without force being exerted. This helplessness of matter is called *inertia*.

57. The Second Law. — The first part of this law (§ 55) may easily be understood — any moving body will go in the same direction that the force takes. Strike a nail with a hammer and the nail moves on as the hammer was moving. If two or more forces act upon a body at the same time, the effect of each force appears in the resulting motion.

Experiment 41. — At the same instant strike a ball *a* (Fig. 30) with two mallets in two directions, *ab* and *ac*. One blow alone would carry it to the right as far as *b*; the other alone would send

it downward as far as *c*. The ball really moves along the line *ad* to *d*; but as *d* is as far to the right of *a* as is *b*, and as far below as is *c*, each force has had its effect.

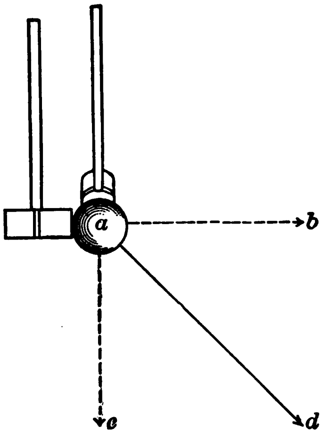

FIG. 30

The second part of the law means simply that the greater the *amount of force* used or the longer the *time* that a force acts, the greater will be the amount of motion caused.

58. The Third Law. — This law means simply that whenever any body exerts force upon another, the second body *in resisting that action* exerts the same amount of force upon the first. If we strike a piece of wood with a hammer, the hammer is stopped by the wood; clearly, the wood exerts force upon the hammer in stopping it. This force is just equal to that exerted by the hammer, for had it been less, the motion would not have been stopped entirely; or had it been more, the hammer would have been driven back. Force exerted in this way, being caused by the *action* of another force, is called *reaction*. Examples of reaction are common: a boat exerts force upon the water as it moves, and the water reacts upon the boat, tending to stop it; in the same way the air reacts upon a train or any moving object; it is well known that a bicycle rider can go faster if he follows a moving shield. In all these cases

note that there would be no reaction if there were not first some action.

Reaction is often very useful. Fig. 31 shows a common wood screw, *A*. As the screw is turned around, the threads push backward upon the wood on the surfaces *a*, Fig. *B*; the wood then reacts upon the threads, driving the screw forward. Many steamships use screw propellers. These, as they turn in the water, exert force backward upon it; then the reaction of the water upon them drives the boat forward.

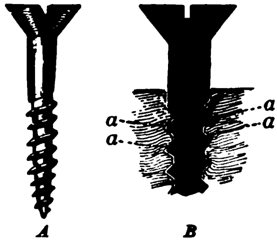

FIG. 31

QUESTIONS

1. State Newton's three Laws of Motion. Tell all that you know about Newton. Try to find out a little more.

2. Give any examples of bodies that seem to set themselves in motion, and then tell what outside force moves them. Why do we not find on earth any examples of constant motion without force being applied?

3. If two equal forces should act upon a body in opposite directions, what would be the result? If the forces were unequal, what would be the result?

4. What is meant by reaction? Could there be any reaction if there were no action? Is there ever an action without reaction?

5. Give examples of reaction. Explain some of its uses. Show how a screw propeller drives a boat.

6. If you strike a wall with your fist, you feel pain. Why? Why does it not give equal pain if you strike a pillow with your fist?

SECTION II

SOME EFFECTS OF NEWTON'S LAWS

59. Inertia. — The tendency of a body to remain in its state of rest or motion has been called *inertia* (§ 56). Owing to its inertia, a body acted upon by force generally starts slowly, increasing its speed as long as the same amount of force acts. We have often received a heavy jarring as a car started violently from a state of rest; this is because the back of the seat runs into us before the body has begun to move.

Experiment 42. — Balance a visiting card on the end of the finger and place a coin upon it, directly above the finger tip. With the other hand suddenly snap the card away edgewise. After a bit of practice, this may be done so as to leave the coin upon the finger. Why does not the coin move off with the card? Slowly push the card off the finger. Note and explain any difference in the behavior of the coin.

60. Momentum. — Inertia also causes moving masses to continue in motion. But as all moving bodies on earth are very soon acted upon by at least one force tending to stop them, it is clear that the ability of any body to keep on moving will depend upon its ability to overcome opposing forces. And this in turn depends upon what may be called its "quantity of motion" or *momentum*. A thrown ball, for example, is set in motion by force exerted upon it at the hand; once out of the hand, its progress depends upon its momentum, that is, the quantity of motion given to it by the arm.

Experiment 43. — Using the same ball, roll it twice over the same surface, once slowly and once with speed. Note the distances that it travels.

Experiment 44. — Now take two balls, one very much heavier than the other (*e.g.* a tennis ball and a bowling ball); roll them over the same surface, starting them at the same speed, if possible. Note the distances traveled.

From these two experiments we see that the momentum of moving bodies depends upon two things — their *mass* (quantity of matter) and their *speed.* Then, in general, we may say that the greater the mass of a body or the faster it moves, the greater is its momentum. The rule is commonly stated as follows: *The momentum of a body is equal to the product of its mass multiplied by its velocity (speed).*

Examples of this law are common. A heavy object is not so easily stopped as a light one moving at the same rate. The faster a train is moving, the more force is exerted by an obstacle which stops it, and the more damage is done. The faster you move in riding a wheel, the farther you can "coast" on a level road. In throwing a ball, the boy who can start it at the greatest speed throws it farthest. To test our skill in throwing stones we carefully select one of proper weight, some being so heavy that we cannot start them with much speed, while some are so light that the greatest speed we can give them will not make up for their lack of mass.

61. Center of Gravity. — A body acted upon by force, so as to move in a straight line, may turn over and over in its flight (as a thrown pebble does); but one point within the body moves on in a straight line, as if

the force had been applied to that point alone. This point is the *center of mass* of the body; it is the point about which the matter of the body seems to be evenly distributed. If now the force of gravity acts upon a body, whether it be supported or whether it be falling freely, the body behaves as if the force were applied at its center of mass. The point may then be called the *center of gravity* (c.g.) of the body. We may say that it is the point in a body at which the force of gravity seems to be applied.

FIG. 32

Experiment 45. — Try to balance a ruler on your finger (Fig. 32). Where is the center of mass of the ruler? Try to balance it upon a pencil point; mark the point. Is this the center of mass? If not, where is it? Compare the quantity of matter on both sides of this point. How do you think the action of gravity upon one side of this spot compares with that upon the other? Where is the c.g. of the ruler? Now hang unequal weights on the ruler, as in Fig. 33. Try to find the c.g. of the whole. Where is it? Compare the matter upon both sides of the point. Where is the center of mass?

FIG. 33

62. Position of the Center of Gravity. — A body acted upon by gravity behaves as if the force were applied at its c.g. alone. If gravity really did act only upon the c.g., that point would, of course, move toward the c.g. of the earth until stopped by some other force. And we find it to be true that any body on earth that is free to move takes such a position that its center of gravity shall be *as low as possible.*

Experiment 46. — Try to balance an egg on its end. Explain the result (Fig. 34). Do the same with a weighted ball or disk (Fig. 35). Hang a ball by a thread, as in Fig. 36, and move it

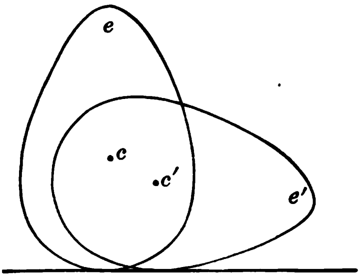

FIG. 34

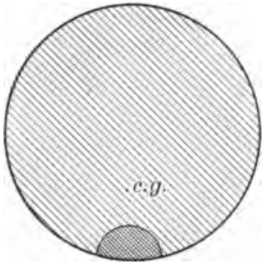

FIG. 35

to a position *a*. Now where is the c.g. of the whole pendulum? Release the ball and note its behavior. When it comes to rest, where is its center of gravity?

63. The Problem of Support. — When a body is falling freely its c.g. moves in a straight line towards the center of the earth, nearly. This straight line is called the *line of direction*. Since gravity acts as if the force were applied along this line, *a body will not fall so long as the straight line from its c.g. to that of the earth passes through its base, or point of support.*

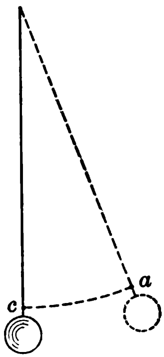

FIG. 36

Experiment 47. — Find the c.g. of your ruler by balancing, and mark the point. Now place the ruler on a table, push it over the edge little by little, and note the position of its c.g. just before it falls.

The *base* of a body is the area inclosed by straight lines drawn from one to another of its outer points of

support taken in order. Fig. 37 shows eight points of support; the base is the area bounded by dotted

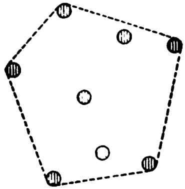

FIG. 37

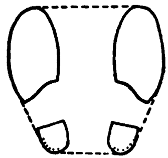

FIG. 38

lines. In Fig. 38 dotted lines show the base of a person standing.

A pencil supported as at *c* (Fig. 39) would be said to be in a state of *equilibrium;* that is, the force of gravity acting on *ac* is just balanced by that acting on *bc*. If *c* were moved a little, these forces would no longer balance, and the pencil would fall in the direction of the greater force.

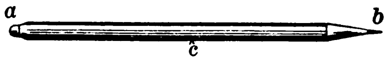

FIG. 39

64. Stability. — A body which is less easily tipped over than another is said to be more *stable*. In general, *the lower the center of gravity or the broader its base, the more stable a body will be.*

Experiment 48. — Stand your pencil on its end; then lay it on its side. In which position has it the broader base? In which is it the more stable?

Experiment 49. — Pile up three books and test the stability of the pile. Then add as many more as you can, and test that. Which pile is the more stable? Why?

Try to balance your ruler, first on its side and then on its end. Which is easier, and why?

In loading carts or in building different structures the heavier material is placed near the bottom, so as to make the c.g. as low as possible. Racing vessels balance their enormous spread of sails by a heavy mass of lead on the keel, which carries the c.g. far down (Fig. 40).

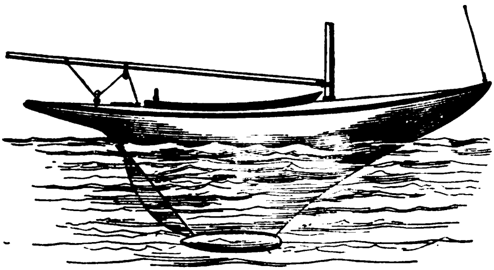

FIG. 40

65. Centrifugal Force. — Since moving bodies tend to go in straight lines (§ 55), it is clear that whenever a body moves in a curved path force must be constantly applied to pull it out of a straight line. Such a force is called *centripetal* because it acts *toward the center* of the curve. But since every action has its *reaction*, centripetal force will be opposed by another force tending to pull the body *away from the center;* this is called *centrifugal force.*

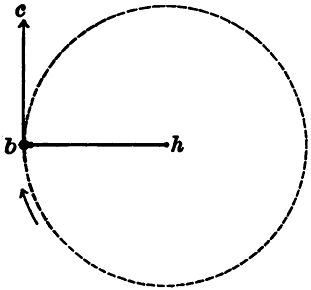

FIG. 41

Experiment 50. — Tie a string to a ball and swing it rapidly about the hand in a circle (Fig. 41). Do you have to use force to hold it? Why? Suddenly let the ball go free, and note its motion. What direction does it tend to take? Try the same thing with a very short string and a very long one. Explain any difference. Note that the two forces exactly balance each other; for while one acts toward and the other away from

the center h, the ball moves no nearer to and no farther from h than the length of the string allows. As soon as you let go, both forces cease to act and the ball obeys the first law of motion (§ 55).

Effects of centrifugal force are common. A pail of water may be whirled in a circle overhead, centrifugal force holding the water against the bottom of the pail so that none is spilled. The same force may cause a carriage or car to tip over in rounding a sharp curve. The wheels are held in place by the track or road, while the c.g., tending to go on in a straight line (Fig. 42), passes outside the base. In all cases, note that *the force is greater if the body moves rapidly or the curve is sharp.* Water would spill from the pail which was swung slowly, and freight trains take curves much more easily than expresses.

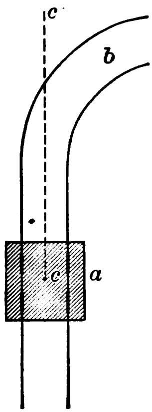

FIG. 42

66. Falling Bodies. — Bodies fall because gravity pulls them. Now since the attraction of gravity depends upon the amount of matter contained in any body, it follows that the greater the mass, the more strongly gravity will pull it; that is, a heavy body will be acted upon greatly and a lighter one less strongly. The result is that *all bodies will fall equal distances in equal periods of time, when not hindered by any other force.* Most bodies do fall equally fast; but a few (such as feathers, leaves, and paper) have so large a surface, compared with their weight, that their falling is greatly hindered. In a vacuum a penny and a feather would fall exactly together (Fig. 43).

Experiment 51. — Drop pieces of different substances (wood, stone, iron, lead, and others) from the same height exactly together, and note whether or not they strike together. Repeat several times, for accuracy.

Compare with these the fall of a leaf or sheet of paper. Note and explain any differences.

FIG. 43

Falling bodies offer almost the only common example of motion which is not opposed by any considerable force; for generally only the air hinders their progress, and its force is not great. Thus it is interesting to note this sort of motion carefully. It has been found that *a body will fall about sixteen feet in one second.* But at the end of that second its *momentum* alone is great enough to carry it about thirty-two feet in a second. The result is that in the second second the body will travel thirty-two feet because of its momentum (or inertia) and sixteen feet by force of gravity, making a total of forty-eight feet. So as it goes on it loses little or none of its momentum and constantly gathers more, as gravity keeps acting upon it; so that *the farther a body falls, the faster it goes.* This is why a long fall generally does more damage than a short one.

67. Pendulum. — A *pendulum* is a device so supported that it is free to swing to and fro about a fixed point. Fig. 44 shows a pendulum, *a* being its point of support (on which it swings) and *b* the weight or *bob.* Lift *b* to the position *c* and let it go; gravity acts upon it, pulling the bob downward toward *e.* At the position

e gravity ceases to pull *b* downward; but the bob then has enough momentum so that it rises to *d* against the opposing force of gravity. At *d* the bob stops, gravity now pulls it to *e*, and it then moves on toward *c*. The path in which *b* swings (*ced*) is called the *arc* of the pendulum. A single complete sweep across this arc is called one vibration. As a pendulum swings to and fro, its arc constantly becomes smaller, and in time the bob comes to rest at *e*. The air offers a slight resistance to the moving body, slowly bringing it to rest.

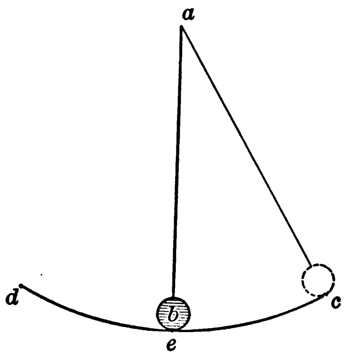

FIG. 44

Experiment 52. — Make two pendulums of exactly equal lengths, by tying string to stones. Make them about two feet long, using stones of very unequal weights. Start them exactly together and compare the rates of their vibrations, that is, the number of swings made by each in a certain period of time. What effect has the weight of the bob upon the vibration rate of the pendulums?

Experiment 53. — Swing a pendulum through a small arc and count its vibrations for 15 seconds. Now swing the same pendulum through an arc much greater, and count its vibrations for 15 seconds. What effect has the length of arc upon the rate of vibration? (The length of the arc makes a slight difference in rate if one arc is much greater than the other, and none at all if both arcs are small — less than 3°.)

Experiment 54. — Make a pendulum 9 inches long and another 36 inches long. Carefully count the vibrations of each for 15 seconds and compare results. Now make one 4 inches long and

another 16 inches long and compare their rates of vibration. How much longer is the second than the first? Which vibrates the faster? How much faster?

What one thing do you find to make a marked difference in the vibration rate of a pendulum? Try to make a statement of the effect of length upon the rate of vibration.

QUESTIONS

1. What is inertia? State examples. Why can you not start a bicycle at once at your greatest speed?

2. What is momentum? Upon what two factors does the momentum of a body depend? How is it generally measured?

3. A rifle ball weighing half an ounce moves at the rate of one thousand feet a second, while a forty-pound cannon ball moves at the rate of one foot per second. Which has the greater momentum? By which would you rather be struck? Why?

4. Why does a woodcutter sometimes fasten his ax in a stick and then invert it, striking the block with the stick uppermost?

5. Why can you not stand an egg on its end? If there were a hole straight through the earth's center from surface to surface, how far into it would a falling body go?

6. Under what conditions will a body be supported from falling?

7. Upon what does the stability of a body depend, and how? Why is it hard to walk upon stilts? Why spread your feet apart to receive a blow in boxing?

8. Explain the cause of centrifugal force. State examples of it. Why do you lean in turning a corner? Why is the inside rail of a track placed lower? What conditions increase centrifugal force?

9. How far will a body fall in one second? in two seconds? Why does a body constantly increase in its speed as it falls? Why is more damage done by a longer fall, as a rule?

10. Describe a pendulum. What force causes it to swing downward? Why does it then swing upward? If no force but gravity opposed its upward swing, how far would it go as compared with its downward swing?

11. Which has the faster vibration rate, a short or a long pendulum? If a clock loses time, would you make its pendulum longer or shorter in regulating it?

12. Since a pendulum is made to vibrate by the force of gravity, would it swing faster or slower on a mountain top than in a valley? (See § 29.)

SECTION III

WORK AND MACHINES

68. Work. — *Work* is said to be done whenever a force causes motion. From this it is clear that work may be measured in terms of the amount of motion caused by a certain force. The *amount of work* done by a force is commonly expressed in *foot pounds.* One foot pound is the amount of work done in raising one pound of matter a distance of one foot against gravity.

The *rate* at which work may be done is sometimes called *power.* The ability of an engine, for example, to do work is expressed as so many *horse power. One horse power is the ability to do thirty-three thousand foot pounds of work a minute.*

69. Machines. — A *machine* is a device which helps man to do work. Note that a machine cannot *of itself* do work; it cannot *make* energy. It can only help in *applying* force to good advantage; and as every machine uses up some of the energy in its own motion, none gives us quite as much *work* as is done upon it.

70. Uses of Machines.—In spite of this fact, however, there are several things gained by the use of machines, which more than make up for this loss in work.

1. *They help man to apply force in a more convenient direction.* The *pulley* (Fig. 45) and *lever* (Fig. 46) are common examples of this. A bit of thought will show how handy it may be, at times, to thus change the direction of motion.

2. *We may use other forces than our own to run them.* Steam engines, windmills, electric motors, water wheels, and treadmills all serve to call such forces to mind.

3. *They help us to store energy to be used at another time.* For example, the spring of a watch, in unwinding, does only the work which was done upon it in winding it up. We could not

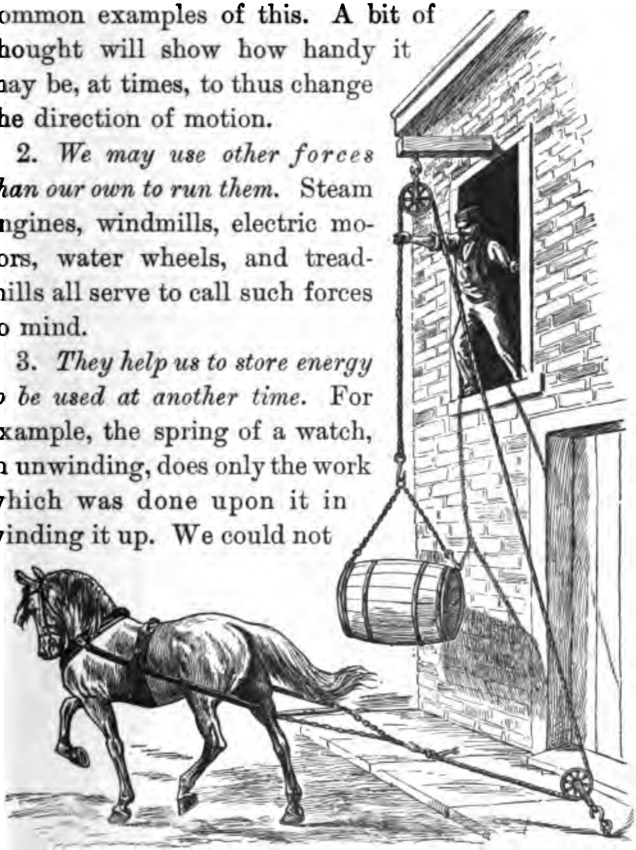

FIG. 45

easily exert force directly upon the wheels all day long.

4. *By their use we may exchange strength of force for speed, and speed for strength of force.* That is, we may

use great force slowly and cause a small body to move rapidly, or use small force rapidly and move a great weight slowly. A few examples of this will be given in §§ 72 and 73.

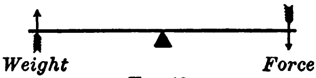

FIG. 46

71. Law of Machines. — The fourth of these uses is one of much importance. It will be more easily understood when we have clearly in mind the following *Law of Machines: The force and the resistance vary inversely as the distances through which each acts.* This means that if a certain force causes motion against a resistance that is greater or smaller than itself, the distance through which the resistance acts must be just as many times smaller or greater than the distance through which the force is applied.

72. Pulleys and Levers. — A few simple machines will serve as examples of this law. Fig. 47 shows one *movable pulley B* attached to a weight *W*; *F* is the point at which the force is applied. Notice that as *F* moves, *W* will move only half as far. From the law, this shows that the force need be only half as great as the weight.

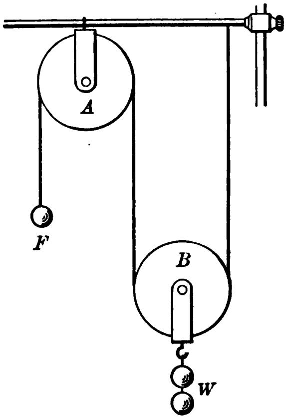

FIG. 47

With two movable pulleys the force would act through four times the distance and lift a weight four times as heavy.

A *lever* is any device having force applied at one point and resistance at another, the whole turning on a point called a *fulcrum*. A crowbar may be used as a lever (Fig. 48). As the force acts from a' to b', the weight moves only from a to b; hence a small force at a' will, in acting through a greater distance, $a'b'$, move a greater weight at a the lesser distance, ab. Also a great force at b could move a lesser weight at b' with greater speed. Fig. 49 shows three classes of levers. In Class I the fulcrum f is between the points where the force p and the resistance w are applied. In Class II f is at the end, w being applied between it and p; this lever gives us a gain in force at the expense of speed. In Class III the force p is applied beween the fulcrum and the resistance, so that we gain in speed at the expense of force.

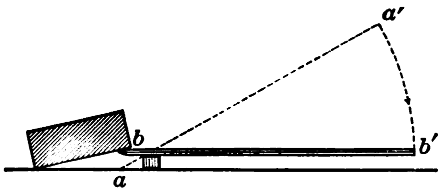

FIG. 48

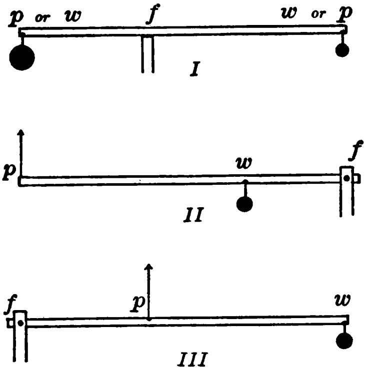

FIG. 49

Experiment 55. — Pulleys and levers are common, and many experiments may be made, according to the time and material available. A movable pulley is not hard to find; but for a

substitute smooth steel screw eyes may be used with small hard thread.

Examples of levers are always at hand. In the following, name the class to which each belongs and state whether we gain in force or in speed by using it: scissors; a common pump handle;

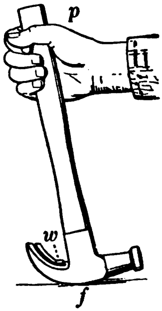

FIG. 50

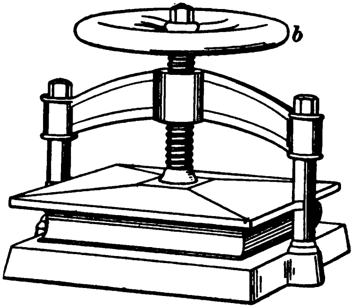

FIG. 51

pincers; sugar tongs; steelyards; nutcrackers; a crowbar when its fulcrum is on the ground beneath a weight; ice tongs; a tinsmith's shears; a wheelbarrow; a claw hammer (Fig. 50).

73. Other Simple Machines. — The *screw* is generally used to gain intensity of force. As the force is applied to the circumference of a wheel *b* (Fig. 51), the surface on which the resistance acts will move ahead only the small width of one thread of the screw. Since the force is applied through a far greater space than the resistance, the gain in force is great.

Fig. 52 shows a *wheel and axle*. The axle is much smaller than the wheel and turns with it. A small force *F* applied on the wheel may move a much greater weight *E* on the axle; but *E* moves proportionally slower than *F*, — that is, a great force at *E* will move

a small weight at F with a gain in speed. In a windlass and a capstan this device is used to gain in force.

Gear wheels (Fig. 53) are used in a similar way. If a large wheel runs in a smaller, the gain is in speed; but

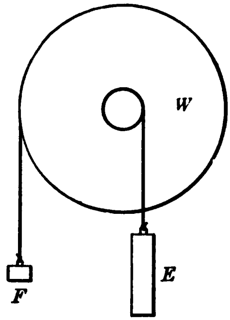

FIG. 52

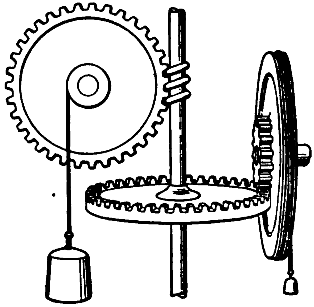

FIG. 53

if force is applied to the smaller wheel, the larger turns more slowly but exerts greater force. Gear wheels are commonly used in machinery.

The *inclined plane* is used for a gain of force at a loss of speed. A plank inclined from the ground to a wagon floor enables a man to get a heavy body into his cart. The more gradual the slant, the more he gains in force required. A *wedge* (Fig. 54) has two inclined faces. It also gains for us intensity of force at the expense of speed.

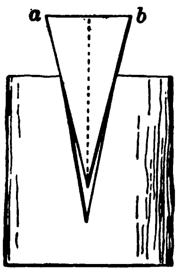

FIG. 54

Experiment 56. — A vise, copy press, thumb-screw, or bolt and wrench may serve to experiment with the screw. For a wheel and axle, any grooved wheel with its axle

fixed so as to turn with it may serve, or one can easily be made. An old clock will furnish gear wheels. An inclined plane can be made wherever convenient, and a thick knife blade will do for a wedge.

QUESTIONS

1. Define work. How is work measured? What is the unit of work?

2. What is meant by power? What is the unit of the rate of doing work? How much is one foot pound? one horse power?

3. What is a machine? Can a machine do work of itself? Does a machine gain or lose work?

4. What, in general, is the use of machines to man? Name four special uses of them. Illustrate each.

5. State the Law of Machines. Show how a lever applies this law. Is a movable pulley used to gain force or speed?

6. Why do tailors' shears have long blades and short handles, while plumbers' shears have short blades and long handles?

7. Why does a bicycle of high gear run harder than one of low gear?

8. What is the advantage gained in using: a single pulley? a windmill? a coiled spring in a watch? the walking beam on an engine? a wheel and axle?

9. State the advantage given by a second-class lever and by a third-class lever. What can you say of the advantage in levers of the first class?

10. Name as many examples of levers in use as you can. Name some familiar uses of the screw and the wedge.

11. Explain the use of gear wheels in machinery.

CHAPTER IV

HEAT AND ENERGY

SECTION I

HEAT

74. Sources of Heat. — *The sun* is a most important source of heat on earth, for without its rays the atmosphere would be intensely cold and we should not have the supplies of wood, coal, and oil which are used as fuels. Other sources of heat are illustrated in the following experiments.

Experiment 57. — Using a convex lens, focus the sun's rays upon a piece of tissue paper for a moment (§ 139). Note their effect on the paper. Name other examples of the heating effect of the sun's rays.

Experiment 58. — *Friction.* File a soft iron nail for a moment and then feel of the filed surface. Saw through a piece of wood and feel of the saw. Rub a metal button on a smooth piece of cloth. Name any examples of bodies heated by friction. The bearings of car wheels often become very hot. Why?

Experiment 59. — *Percussion.* Hammer a small piece of lead for half a minute and feel of it. Repeat this, using a soft iron nail. Did you ever pick up a rifle bullet that had just been flattened by striking an iron target? Think of other cases of heating by percussion.

Experiment 60. — *Compression.* Pump air into a bicycle tire for a few moments and then feel of the pump. Can you discover evidence of heat being developed by compression?

Experiment 61. — *Chemical Action.* Pour a little hydrochloric acid upon bits of zinc in a test tube. Very carefully and slowly

pour a little sulphuric acid upon water in a test tube. In each case feel of the glass around the liquid. What do you discover about chemical action?

Heat is very commonly caused by *combustion* or burning. This is a sort of chemical action and is treated in § 260. *Electricity* is also a common source of heat; its heating effects are shown in electric lights and are used in furnaces and heaters. Its action is explained in § 192.

75. Theory of Heat. — In studying the molecular theory (§ 11) we learned that the molecules of all matter are thought to be in a state of constant *vibrating motion.* Naturally we may suppose that in some bodies the vibration is more rapid than in others; also that in the same body the motion may be greater or less at different times. The *heat* of any body is believed to vary with this vibration of its molecules, as stated in the *theory of heat* as follows: *The heat of a body is the energy of vibration of its molecules; the faster they move, the warmer is the body.*

With this theory in mind, the results obtained in Experiments 58 and 59 may be easily understood. Rubbing, in the one case, and pounding, in the other, simply caused the motion of the molecules to become more rapid, and the masses became warmer. The theory applies also in the other cases.

Within certain limits we can discover differences in the heat of things about us; we say that a body feels more or less "warm." It must be carefully noted, however, that this is only the *effect* that heat produces upon

our sense. We must not judge of the nature of heat by this single effect, for it is only one of many different effects. It is important, in order to understand the further study of this chapter, that we fix firmly in mind the idea that *heat is a form of energy* — the energy of molecular motion.

76. Cold. — *Cold means simply the absence of heat.* Since heat is molecular energy, and the molecules of every mass are in motion, it follows that no body has absolutely no heat. Thus complete cold is unknown. We use the word *cold* to express a condition of *less heat* than some other substance has.

77. Temperature. — *Temperature* is the condition of a body with regard to the intensity of its heat. If a body is warmer than another, we say that it has a *higher temperature;* if colder, we say its temperature is *lower.*

Care must be taken to avoid calling temperature the "quantity of heat" of a body. A cupful of water might have a higher temperature than water in a kettle; but at the same time the kettleful would have a greater quantity of heat, because there is so much more water. Temperature is the *average heat of each particle,* while quantity of heat is the average of each particle multiplied by the number of particles.

78. The Thermometer. — The *thermometer* is a device for measuring temperature. It does this by expressing, in degrees, how much warmer or colder a body is than some other substance taken as a standard. Two thermometers are in common use, the Centigrade and the Fahrenheit.

The only difference is in the marking of the *scale* of degrees, as shown by the two side by side in Fig. 55.

The *Centigrade* scale is largely used in scientific work. Its standard is *freezing water* and is marked *zero* (0).

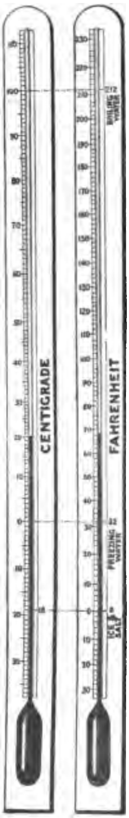

FIG. 55

The temperature of boiling water is marked one hundred (100). The space between these marks on the scale is divided into 100 equal parts, each called a *degree* (°).

The *Fahrenheit* scale is most commonly used by us. Its *zero* is the temperature of *a mixture of ice and salt*, and the boiling point of water is 212°. Water freezes at 32° above zero on this scale.

Experiment 62. — Carefully test these substances (freezing water, boiling water, and ice and salt) with both thermometers. Compare the temperatures of several substances on both scales, and try to discover a rule for changing one reading to the same temperature on the other scale.

79. How a Thermometer is made. — A small tube of hairlike bore, having a bulb at one end, is partly filled with *mercury*. *The air is removed*, because its pressure would prevent the mercury from rising, and *the tube is completely closed.* Mercury will *expand* when heated (see § 81) and shrink when cooled, so that as the temperature rises or falls, the mercury moves up or down the fine tube. Assuming that its expansion is uniform, we may compare temperature changes by comparing the distances that the mercury column rises or falls.

To mark the scale, the bulb is put into ice, and the point to which the mercury rises is marked 0; the bulb is then put into steam or boiling water, and the point to which the mercury rises is marked 100. The space between is then divided into equal parts, and the marks may be continued above 100 and below 0. This gives a Centigrade scale. How would the marking of a Fahrenheit scale differ from this?

QUESTIONS

1. State the theory of heat. Give examples which seem to show the truth of this.
2. What is the great source of heat upon earth? Can you show how the heat from coal once came from the sun?
3. What is meant by cold? Is any body absolutely cold? If a body were entirely cold, what would be the condition of its molecules?
4. Define temperature. Carefully explain the difference between temperature and quantity of heat.
5. For what is a thermometer used? Explain how the thermometer is made and how it acts.
6. What two thermometers are in common use? Which one do we use daily? What is the standard in each? On which scale are the degrees the shorter?
7. Name and describe the more common sources of heat.

SECTION II

EFFECTS OF HEAT

80. The Effects named.—In general, the effects of applying heat to bodies are four in number,—*chemical effects, electrical effects, changes of volume, and changes of state*. The first two of these effects will be treated in later chapters; we shall now consider only changes of volume and of state which are caused by the action of heat.

81. Changes of Volume. — When, without more matter being added, a body grows larger, it is said to *expand;* when, without losing any of its particles, a body grows smaller, it is said to *contract. As a general rule, masses expand when they are heated and contract when cooled.*

Experiment 63. — Secure a hollow metal ball which exactly fits into a ring (Fig. 56). Heat the ball, and see if it can be forced through the ring. Heat both ring and ball and try them again; they should fit. Cool the ball and heat the ring. How do they fit now?

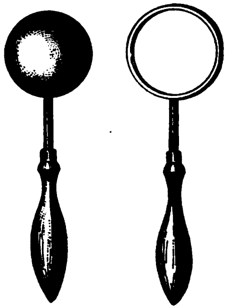

FIG. 56

Carefully measure a long iron nail. Heat it thoroughly and measure again. Is it longer or shorter?

Experiment 64. — Fill a test tube with water and fit a stopper *lightly* into its mouth. Heat the water and note the result. Explain this. (Do not crowd the stopper or heat the water too highly.)

Fill a long narrow tube with hot water; let it cool to an ordinary temperature and note any change in volume.

Experiment 65. — Arrange a tube so as to run through the stopper of a flask or bottle, into a vessel of water, as in Fig. 57. Heat the flask and explain what you observe. What is in the flask? What change does it undergo?

Now remove the heat, watching the tube carefully. As the flask cools, what change takes place in its contents? Try to account for what you notice.

82. Uses of Expansion and Contraction. — From these experiments we see that liquids and gases may expand and contract as well as solids. The value of this will be seen when we study convection (§ 91). In the case of solids this principle is commonly used to good

advantage, for the force exerted by a body in expanding or contracting is very great. To make a wagon tire fit tightly, a blacksmith often puts it on after heating it; upon cooling, it contracts and fits the wheel closely. Similarly the parts of boilers, bridges, and other steel

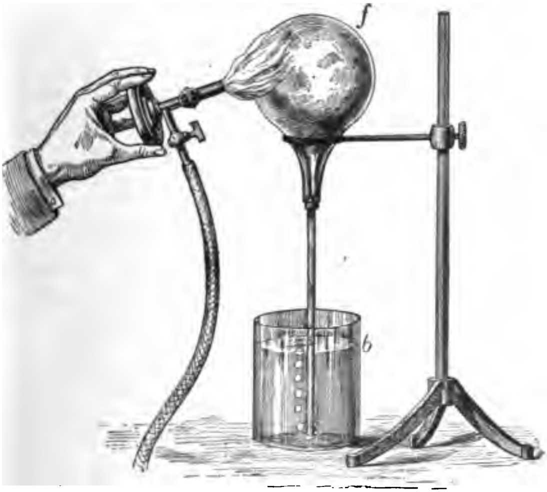

FIG. 57

structures are fastened with rivets which are put in while red-hot; these cool and contract, drawing the parts tightly together.

83. Exceptions to the Rule. — A few substances do not obey the general rule for expansion and contraction. Of these, water is a common example. We have seen ice floating upon water, which shows that it is lighter than the liquid; but as ice is only frozen water, we know that it must have expanded upon cooling.

Experiment 66. — Fill two thin bottles with water and cork them tightly. Heat one and allow the other to freeze. The water may be left to freeze over night; but do not try to heat the tightly closed bottle without help from your instructor. Note and draw conclusions from the results.

Careful study has shown that *water has its smallest volume at 4° Centigrade.* If heated above or cooled below that point, it expands.

84. Changes of State. — Early in our study we learned that solids change to liquids and liquids to gases upon being heated; also that gases become liquids and liquids change to solids when cooled (§ 9). In some substances these changes occur at ordinary temperatures, and are common enough. In other substances, however, the changes would need such a high or low degree of heat that they are seldom or never accomplished.

The change from a solid to a liquid is called *melting*, *fusion*, or *liquefying;* the change from a liquid to a solid is called *solidifying*. The temperature at which a solid substance liquefies is the same as that at which it solidifies from a liquid state. *Vaporization* is the change from a liquid to a gaseous state; the temperature at which a substance vaporizes is called its *boiling point.*

In a large number of substances *pressure* upon them raises the temperature at which these changes of state occur. Thus water, which can usually be no hotter than 100° C., rises to a much higher degree in a locomotive boiler, where it is under pressure from the steam. With substances such as ice, which contract when they are melting, pressure lowers the melting point. Thus a block of ice receives the imprint of a dish which rests

upon it heavily, the ice beneath the dish melting faster than the other parts.

85. Evaporation. — We know that a moist cloth soon dries if hung in warm air; also that a thin layer of water in a dish or on some hard surface soon disappears. Clearly the liquid must have gone somewhere. But did it pass off in a liquid state? If so, we should probably have seen it go. We have to suppose, then, that it *changes into a gas and passes off into the air*, and we say that it has *evaporated. Evaporation* may be defined as that sort of vaporization which goes on quietly at ordinary temperatures.

Note that evaporation, not being produced necessarily by boiling, depends partly upon the ability of the atmosphere to receive the vapor. Of course some substances vaporize more easily than others, but in general the conditions which aid evaporation are conditions in the air surrounding the liquid. Warm air can hold more vapor than cold; dry air can naturally take on more than that which is moist or *humid;* and evaporation goes on faster when the atmosphere is in motion. Thus the best conditions would be *warm, dry, moving air.*

Experiment 67. — Try these different conditions with small amounts of water. Also use such liquids as alcohol, ether, and naphtha. Blow upon them, and see if there is any faster evaporation. Why put damp clothes in a warm place to dry? Will clothes dry when frozen? Do they dry better on windy days?

86. Condensation. — The amount of vapor which air can hold varies with its *temperature;* other things being equal, *the warmer the atmosphere, the more vapor it can*

hold. When air at any temperature holds all that it can, it is said to be *saturated*. If now it be somewhat cooled, this air can no longer hold all the vapor that is in it, and some will change back to its liquid state. This change is called *condensation*. The condensed water vapor may then float about as tiny liquid drops; small masses of these drops may pass to another place and there evaporate again, like the cloud from a locomotive; while large masses would form a *fog* or *cloud*. If the drops were large they would fall as *rain*.

Experiment 68. — Put ice or snow into a pitcher and take it into a warm room. Watch the outside of the pitcher, and explain. Breathe upon a cold piece of glass. Why does frost form on the inside of a window pane? Why do we "see our breath" in cold weather?

87. Distillation. — Important use is made of these principles (§§ 84–86) in separating substances from each other or from impurities. Since different sorts of matter vaporize at different temperatures, a mixture may be heated to the *low* boiling point of one substance without vaporizing the others; the gas from this one may then be cooled, giving us the desired liquid or solid, free from the others. The process is called *distillation*.

Experiment 69. — A device for distillation may be arranged as in Fig. 58. Instead of the *condenser c*, a long tube of glass or metal may be run through a trough in which cold water is flowing. Fig. 58 shows the condenser as generally used in distilling. Muddy water may be boiled in a closed flask *f*; the steam runs through a tube *t* which carries it to the coiled tube *e* in the condenser. Cold water running into *c* from a pipe *p* surrounds the coiled tube *e* and runs out at *o*. The steam in *e* is cooled and

condensed by the cold water around it, running out at *n* as water. Since only steam passed from *f* to *e*, the water should come from the tube clear and pure. It is called distilled water.

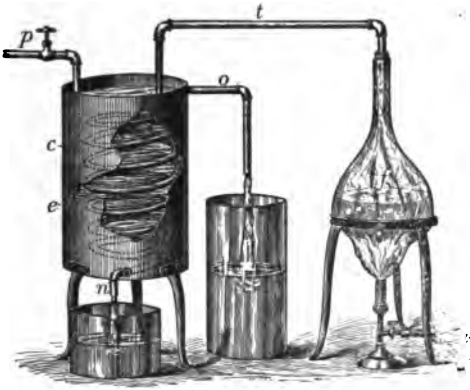

FIG. 58

Distillation is used on ocean steamers to supply water for the boilers; salt sea water would rust them badly, but distilling removes the salt. The process is also used in making alcohol and liquors, flavoring extracts, perfumes, and many other compounds.

88. Latent Heat. — The temperature at which ice melts (32° F.) is the same as that at which water freezes. If a piece of ice is put into a vessel and slow heat applied, the ice changes to water; but so long as any ice remains, the temperature of the water remains the same as that of the ice. In other words, though much heat is applied to the mass *its temperature does not rise.* This fact was early discovered, and the name *latent* (*i.e.* hidden) was given to the heat which thus seemed to disappear.

The same thing occurs when other substances are changed from solids to liquids, or from liquids to gases. It is also true that the heat thus taken into a body is

given out again whenever the mass changes back to its solid state, or from a gas to a liquid. Farmers often protect their supplies by taking tubs of water into their cellars; when it is cold enough to freeze the water, the heat given off by the freezing liquid keeps the cellar warm enough so that the vegetables do not freeze.

Experiment 70.—Into a glass dish put several pieces of ice; carefully note the temperature of the ice. Now apply heat slowly, testing the temperature of the mixture from time to time as the ice melts. Just before the last bit melts, remove the source of heat, and when all is liquid test the temperature again. Was heat given to the mass in the dish? How do you know this? Did this heat raise the temperature of the whole? What did it do

QUESTIONS

1. What are the common effects of heat? Does heating always produce all of these effects in a body at the same time?

2. Define expansion and contraction. How in general is the volume of a body affected by heat? Do liquids and gases expand and contract like solids? Name any uses of expansion and contraction that you have seen.

3. Why does ice float? Show how water freezing in a crevice may break a rock. What is the rule for expansion in water?

4. Give the general rule for changes of state due to heat alone. What is meant by the words *liquefying*, *solidifying*, and *vaporization?* What effect has pressure upon changes of state? Compare the temperature of water boiling in a locomotive with that of water boiling in an open dish.

5. Define evaporation. What conditions assist evaporation? Why put your clothing in a warm place to dry?

6. When is air said to be saturated? If it is then cooled, what happens? How are clouds formed? What is a cloud made up of? Show how rain is formed in the cloud masses.

7. Explain distillation. To what important uses is it put?

8. **What is meant by latent heat? What work is done by this heat? Since the temperature of ice is 32° F., and ice melts at 32° F., why does a block of ice in an ice house remain solid through the summer? Why does not ice on a pond melt at once when the sun strikes it? Why does a snowstorm often end in a storm of rain?**

SECTION III

TRANSFER OF HEAT

89. Methods of Transfer. — We know that water standing in a room becomes the same in temperature as the air around it; that if a warm body be placed near a colder one, it loses some of its heat, while the other becomes warmer; that the earth is warmed from the sun; and that a room may be warmed from a stove or radiator, or a whole house even may be heated from a furnace in the cellar. These things show that heat must be able to travel from one place to another. Heat may be *transferred* (carried from place to place) in three different ways, — by *conduction*, *radiation*, and *convection*.

90. Conduction. — *Conduction is the transfer of heat from one particle to another which touches it, without change of relative position of the particles.* Heat may flow from place to place in the same mass, or from one body to another which touches it, by conduction. Each vibrating molecule is supposed to increase the energy of vibration of those which it touches; they in turn give greater energy to those that they touch; and so on. But each molecule remains in its place; though it may vibrate faster, its position among the others is not changed.

Experiment 71. — Put an iron rod or wire in a hot fire. After a few minutes, try its temperature at different points, beginning with the end that is farther from the fire. Let it remain and see if it grows hotter throughout.

Substances which allow heat to pass through them easily in this way are called *conductors* of heat. In general, solids and liquids are good conductors as compared with gases, which are very poor. *Metals* are usually very good conductors, while wood and cloth conduct heat but poorly. Stove lifters and pokers often have wooden handles, for this reason; felt also is used around steam and water pipes to keep the heat in.

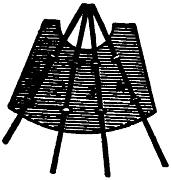

FIG. 59

Experiment 72. — Arrange four metal wires (*e.g.* iron, copper, brass, and German silver), as in Fig. 59. Apply heat at A, and note the order in which the other ends become hot. Compare the conducting power of the different metals.

Experiment 73. — Find the temperature of the air in the room, and of water which has been in the room a long time; they should be the same. Now put your hand into the water. How does it feel? Which takes heat out of your hand faster, air or water? Which is the better conductor?

Experiment 74. — Boil the top of water in a test tube, as in Fig. 60. Note how long it is before the bottom becomes hot, and compare with a similar length of iron.

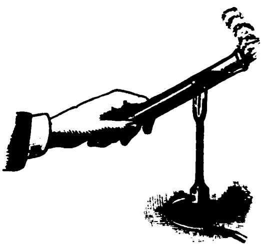

FIG. 60

91. Convection. — *Convection is the transfer of heat from place to place by the change of position of heated particles.* Since the molecules of solids are not free to

move about, convection is limited to *liquids and gases*. The direction of movement in convection is upward and downward, warmer particles rising and cooler ones falling. As any portion of a fluid body becomes heated it expands, that is, its particles are farther apart; thus the heated portion becomes lighter than the cooler parts of the fluid around it. Of course *gravity* will then pull the heavier parts downward, and the lighter heated portion will be forced upward.

Experiment 75. — Heat a can of water. Before it is entirely warmed through test its temperature at different depths.

92. Uses of Convection. — Fluids, especially gases, are such poor conductors that they can only be heated very slowly by conduction. In fact, dry air is so poor a conductor that it would hardly carry heat at all; we should have to live constantly in very cold air, if it were not for convection. The rise of heated air from a lamp chimney (Fig. 61), which may be easily noted, shows us how readily air may be set in motion; and in just the same way the warm air above a stove or other heater rises and is spread about. Similarly the water in a kettle is quickly heated by convection; the warmer parts, constantly rising to the top as they become heated, allow the colder portions to receive heat at the bottom. Fig. 62 shows how the rise of warm air above a fire keeps it supplied with a good draught of fresh air from below.

FIG. 61

Without convection, stoves and lamps would need to be blown from beneath all the time. Practically all *winds* are started by convection, heated air somewhere being set in motion by cold air pressing upon it.

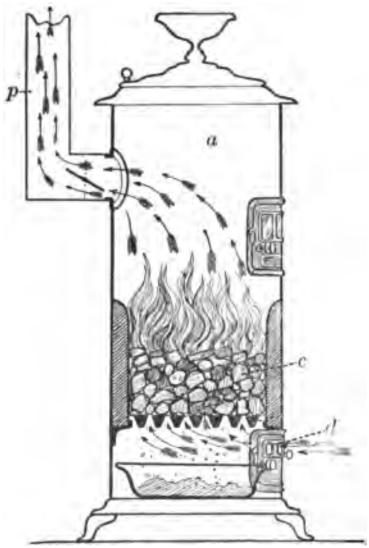

FIG. 62

93. Radiation. — *Radiation is the transfer of heat by vibrations of the ether.* This statement may perhaps mean very little as it stands, because it brings up an idea which may be new to most of us. The transfer of energy by radiation is so very important, however, that a great effort should be made in trying to understand it.

First of all, an example of the transfer of heat by *radiation* may be helpful. If a fire be kindled in a cold room, *objects* in the room may become warm some time before the air between them and the stove is equally heated; clearly the heat is not conducted by the air to the objects, nor does it travel to them by convection. Similarly the *sun's* heat warms the earth; yet we know that the space between the sun and the earth contains no matter that is dense enough to carry heat by conduction or convection.

In order to explain how heat can be thus transferred, scientists assume that *all space* is filled with some *medium* which is *very elastic*, and they call it *the ether*. Through this very elastic medium *energy* may travel at an exceedingly great speed. The energy is supposed to be transferred by the vibrating of the ether. From its source, then, *energy may travel through the ether* in straight lines; and this traveling energy is called *radiant energy* or *radiation*. It does not heat the ether through which it travels, but *upon reaching certain bodies of matter* the radiant energy may stop and become changed into *heat* in those bodies, the degree of heat being greater or less according to the nature of the substance.

We must understand, of course, that this is only supposed to be the method by which heat is radiated. The ether is not a substance that can be seen, felt, or weighed, and it does not conform to our usual ideas of matter. Still, scientists are so very sure that the ether really exists that we have come to accept it as a fact and to discuss its behavior without any doubts or hesitation. The *source* of heat radiation must of course be a heated mass, and in giving off the radiant energy it loses some of its own energy or heat.

QUESTIONS

1. In what ways may heat be transferred?

2. Define conduction. Explain how heat is conducted through a body. What is a conductor? Are solids, liquids, and gases equally good conductors? Why are wooden handles better than iron for stove lifters?

3. Explain the cause of convection. How is it different from conduction?

4. Name some uses of convection. In what sorts of matter is convection possible? Could a kettle of water be heated if placed beneath a fire? Show how convection is useful in stoves and lamps.

5. How does radiation differ from conduction and convection? Are all substances heated with equal ease by radiation? Which is warmer in summer, a tar walk or a grass lawn side by side? Why?

6. Carefully explain radiant energy and the ether.

SECTION IV

ARTIFICIAL COLD

94. How Masses are cooled. — Since cold means simply *absence of heat*, it follows that *cold* cannot be put into a body, but *the only way to cool any mass is to take away some of its heat.* This is commonly done by putting the thing near some cold substance, when its heat will gradually flow into the other (§ 89). In this way, things put into an ice box give up some of their heat to the ice; thus the ice is slowly melted and the substances become cool. We feel cold on a wintry day, because heat is rapidly taken from our bodies by the cold air about us; and we wear clothing not to keep out the cold but to keep the heat in.

95. Artificial Cold. — The common method of cooling does not give us very low temperatures, for no substance is naturally colder than the lowest degrees which climate allows. *Very low temperatures are obtained by performing some process which requires heat, near the body from which we wish the heat to be taken.* The processes generally used are *melting* and *vaporization.*

96. Cold by Melting. — The change from a solid to a liquid state requires heat. If it can be performed by some means *other than directly applying heat*, the substance will *take in* the necessary heat from wherever it can be had. For example, salt causes ice to melt, but the melting ice must have heat in order to liquefy; thus, if the ice and salt be put into an ice-cream freezer, the heat will be taken from the cream, causing it to become solid.

Experiment 76. — Put a tablespoonful each of *sal ammoniac* and *ammonium nitrate* (solid salts) into a tumbler of water. At once stir the whole with a small test tube containing water (Fig. 63). The solid salts dissolve (becoming liquid) very fast. Does this process require heat? From what is this heat taken? With what result?

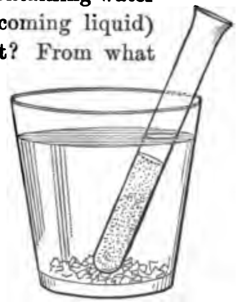

FIG. 63

97. Cold by Vaporizing. — In the same way, liquids in turning to gases take heat from substances around them.

Experiment 77. — Pour a small amount of alcohol on the hand, allowing it to evaporate. Does it feel cold? Blow it, to make it vaporize faster. Does it feel colder? Try naphtha, ether, or chloroform in the same way. Do bottles of these liquids seem cool to the touch?

The making of *artificial ice* depends upon this principle. Liquid ammonia can be kept in its liquid state only under great pressure; as soon as the pressure is removed, the ammonia *vaporizes* rapidly, *requiring much heat*. This is done near boxes of water, so that *the heat is taken from the water*, freezing it.

Very low temperatures are reached by similar means; even air and other gases have been liquefied when put under great pressure and cooled by other gases expanding around them. The temperature of *liquefied air* is about 191° C. below zero. It has been computed that *absolute cold* (*i.e.* a condition of no heat at all) would be reached at 273° C. below zero, or −459.4° F. The lowest degree that has been reached is about −250° C.

QUESTIONS

1. Can cold be put into a body? How may a substance be cooled? In what way is this commonly done?

2. Do any substances naturally have very low temperatures? Why? What must be done in order to get very low degrees? What two processes are commonly used?

3. Explain how cold is produced by melting. Show how this method is used in freezing cream.

4. State examples of cold produced by vaporization. How, in general, is artificial ice made?

5. How are gases liquefied at low degrees? What is the condition of absolute cold? At what degree would it be reached?

SECTION V

ENERGY

98. Transformation of Energy.—We have learned that energy is the ability to cause motion (§ 5), and we know that this ability *may be given from one body to another.* For example, a coiled spring may lie at full length on a table with no ability to cause motion; but press its coils together (Fig. 64) and it is then able to exert force to get back to its former length. Energy is put into the

spring from the muscular energy of the arm in pushing. Not only may energy be transferred from one body to another, but *one kind of energy may be changed to a different kind* either in the same body or in passing from one to another. Thus, muscular energy in the arm became elasticity in the spring.

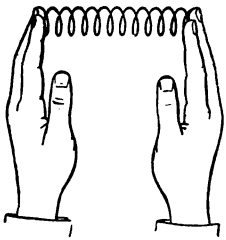

FIG. 64

Experiment 78. — Into a strong test tube put an inch or two of water. Find a stopper which exactly fits, so that it may move up and down *easily* within the tube. Push it down upon the water lightly. Now heat the water slowly and with caution. As the heating continues, what do you notice? What sort of energy is being used? What is its effect upon the water? Is energy imparted to the water? What is the proof of this?

Experiment 79. — Put a piece of zinc into a test tube with hydrochloric (muriatic) acid. Chemical action at once begins, the zinc acting upon the acid. Feel of the tube from time to time. Into what form of energy is the energy of chemical action being transformed?

Many other experiments and common happenings show that one form of energy may be changed into a different form in the same or in another body. This change of energy from one form to another is called *transformation of energy*. The following principle is generally believed by scientists: *All forms of energy are so related that any kind may be transformed into any other kind.* The study of these changes is an interesting and important part of physics.

99. Heat as a Source of Energy. — The use of heat as a source of mechanical motion has become very common.

Various *engines*, run by steam, hot air, gas explosions, and naphtha, which are now widely used for many purposes, get their energy from heat. In all these engines the force which finally causes the motion is the *expansive force* of some *gas;* but the *energy* which causes the gas to expand is supplied by *heat.*

100. The Steam Engine. — It is of course well known that if a certain amount of a liquid be changed to a gas, *the volume of the gas will be far greater than that of the liquid.* But if this change is made in a closed vessel,

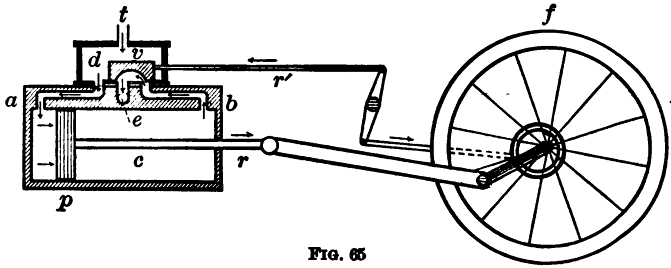

FIG. 65

the gas will exert great force in trying to expand to its larger volume. A *steam engine* makes use of the force exerted by *steam* when thus trying to expand.

Heat is applied to *water* in a *boiler*, changing it to steam. This steam is at once led to a *cylinder* where it is allowed to expand, first on one side and then on the other of a *piston, p* (Fig. 65). The figure (65) should be carefully studied until the action of the engine is plain. Steam comes from the boiler to the *steam chest d* through a pipe *t.* A *valve v* moves to and fro in *d*, allowing the steam to pass to the cylinder *c*, first to one end and then the other through *ports a* and *b.* The arrows show

Plate III. A Steam Locomotive

the direction of flow when *a* is open; the piston *p* is forced toward *b*, driving out the steam in that side through an opening *e* to the air outside. Follow the motion of *p* as it moves the rod *r* and turns the *fly wheel f;* notice how this causes the valve *v* to move. When this valve has moved to the position shown in Fig. 66, steam goes through *b* to the cylinder, moving the piston the other way and driving out the used steam through *a*.

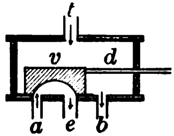

FIG. 66

101. Other Heat Engines. — The *locomotive* is a steam engine which moves itself on a track; it carries a boiler and two engines (one on each side) all on one frame. The *steam turbine* contains a set of blades similar to a water wheel; these blades are fastened to a shaft and are made to turn around by jets of steam which strike them. *Gasoline engines* explode a mixture of gasoline and air; the energy of the explosion moves a piston which is joined to a fly wheel. *Naphtha engines* burn naphtha, using that heat to vaporize other naphtha in a coiled tube. This vapor is allowed to expand in cylinders, so that the action is somewhat like that of steam engines.

QUESTIONS

1. Can energy be given from one body to another? If so given, would the body which gave it still contain as much as it had before?

2. What is meant by transformation of energy? From what source do we get our muscular energy? Can this energy be used so that we feel its loss?

3. State examples of transformations of energy. What form of energy is now commonly used in producing motion?

4. State the principle upon which heat engines are based.

5. Describe the steam engine, explaining its manner of working.

6. Name other heat engines, briefly telling how they apply heat in causing motion.

7. What fuels are commonly used in these engines as sources of energy? How were these fuels made? Where did the necessary energy come from? What, then, is the great original source of the energy now commonly used on earth to cause motion?

CHAPTER V

SOUND

SECTION I

EXPLANATION OF SOUND

102. Wave Motion. — There are two sorts of motion, — the movement of a body from one place to another, and *motion from particle to particle through a body.* The latter is called *wave motion* or a *wave.* The motion of any single particle in a wave is called *vibration* or vibratory motion. As a wave reaches any particle in a body,

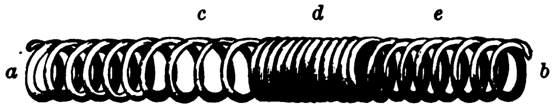

FIG. 67

that particle is moved from its place, giving its motion to the next one and returning again to its position.

Experiment 80. — Fasten a coiled spring (Fig. 67) by both ends, *a* and *b*. Pick up the first few coils and crowd them together (see *d*) at *b*; the part just ahead of these condensed coils is spread apart, as in *c*. Now let go the coils. The condensed part *d* travels quickly toward *a*, the separated coils going ahead (*c*) and the coils behind *d* being left as they were at the start, *e*. Each particle, as the wave goes along, first moves toward *b*, then toward *a*, and finally returns to its place, completing one vibration.

The body through which a wave passes is called the *medium* of the wave. The vibrations producing a wave

may be of different sorts; in the spring (Fig. 67) the vibration of each particle is parallel to the direction of the wave motion itself, while Fig. 68 shows each particle

FIG. 68

vibrating (*ab*) at right angles to the direction of the wave, like ripples on water. A *wave length* is the distance from one particle to the next one which is in the same state of vibration, as *bd* (Fig. 69). The *rate of vibration* is the number of vibrations which pass a given point in one second.

103. Definition of Sound.—We are familiar with wave motion in water; any disturbance—the wind, a pebble thrown into it, a moving boat or animal—is enough to cause ripples, even if slight, so that a body of water is rarely free from waves. In just the same way *the air* is constantly vibrating. Any slight disturbance sets up wave motion in the elastic atmosphere, and because there are so many more disturbances in air than in water, there are also many more sorts of waves all the time. Of course we cannot *see* these waves, and we can

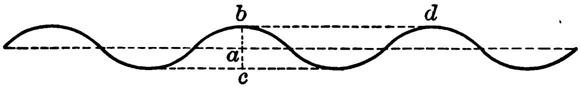

FIG. 69

feel only the greater ones. How then can they be discovered? Nature has given us an ear for that purpose; we *hear* these waves in the air, and we call the sensation

sound. In other words, ***sound is the sensation made by waves in the air striking the ear.*** In order to get used to this idea, let us study it a bit further.

104. Sound Waves. — Once more let us consider how small a motion in still water will cause ripples to spread far away over its surface. Now, recalling the fact that air is perfectly *elastic*, it should not be hard to see that waves may likewise be caused in the atmosphere by the many motions which are always disturbing it; and, as in water these waves may be large or small, so in the air there are long ones and short ones, according to the motion which caused them. Not all of these waves can affect the ear to produce sound, some being too long and some too short. Those waves which can produce sound in the ear are called *sound waves.*

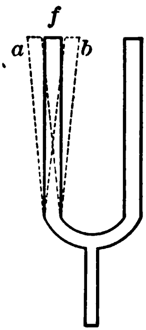

FIG. 70

105. The Cause of Sound Waves. — A tuning fork (Fig. 70) may be used in showing how sound waves are started, for its vibrations can be easily seen.

Experiment 81. — Strike a tuning fork sharply on a desk and at once look for any vibrating (buzzing) of its prongs. Again strike the fork; then hold its prongs downward so that they lightly dip into water. Do you see anything to show that they vibrate?

Let us see how this motion causes sound waves in the air. The prong *f* (Fig. 70), in vibrating, moves rapidly to and fro between *a* and *b*. As it moves toward *a* the air in front of it is *condensed*, but is quickly *rarefied* as the prong flies toward *b*. Thus the prong,

rapidly moving to and fro, causes many condensations and rarefactions to follow each other away from the prong. These pulses of air are sound waves. In Fig. 71 the condensations (*A*) and rarefactions (*B*) are supposed to be moving away from a vibrating bell.

106. Vibrating Bodies. — It will perhaps be hard to grasp at once the idea of sound as merely a ***sensation***,

FIG. 71

which reports to the brain the *vibrations* in matter about us. One difficulty is that whereas there is no end to the sounds we hear, it is not often we can discover any vibration in the body which caused a sound. Tuning forks, violin strings, piano wires, bells, and a few others show vibration plainly, but in many cases there is none to be seen. Sometimes these vibrations are

largely caused in the air itself, as when a gun is fired or we clap our hands; often the motion is so great that we lose sight of the little vibrations, as when a load of rocks is dumped. In some cases the motion may be *felt* even if we cannot see it.

Experiment 82. — Hold a pan in the hand and strike it. Can the vibration be felt? Strike several sharp blows on an iron bar held in the hand. Do you feel a tingling sensation? Blow a horn and touch it lightly with the finger. Sometimes the sound waves from a distant blast or a heavy cannon will shake the windows which they strike.

At least we must understand that *sound* occurs only in the ear. However a vibrating body may arouse sound waves in the air, it is still nothing but a vibrating body. There is no *noise* in a gun which is fired, and no *sound* in a piano — nothing but *motion.* To be sure, we are made aware of the motion because of the sound that it produces in the ear; but the source of this sensation is still only a body in vibrating motion.

QUESTIONS

1. What two sorts of motion are there? What is a wave?

2. What is a vibration? Explain how each particle moves during one complete vibration.

3. Define a medium. Define wave length and rate of vibration.

4. Define sound. Of what use is this sensation to us?

5. What are sound waves? What is the first cause of waves in the air? Are all of these waves alike? Are they all sound waves?

6. Show how a vibrating fork may cause waves in the atmosphere. What property of air makes it a good medium to carry sound waves?

7. Name some bodies whose vibrations can be seen. Name some whose vibrations can be felt. Why can we not see the vibrations in all masses?

8. Where is sound located? Is there sound in a vibrating body or in the air?

SECTION II

TRANSMISSION OF SOUND WAVES

107. Different Media. — Sound waves may travel through other substances than air, though they usually pass through the air a short distance anyway, before reaching the ear. *In general, solids carry sound waves*

FIG. 72

better than liquids, and liquids better than gases. That sounds are sharper under water is known to every boy who swims, and we know that sound waves come through the iron rails of a track much faster than through the air.

Experiment 83. — Listen at one end of a log or an iron rail while some one scratches the other end with a pin. Do the same with several solids.

Experiment 84.—Punch holes in the bottom of two clean tin cans, and to each tie one end of a stout string about one hundred feet long. Each taking a can, let two pupils separate until the string is pulled tight (Fig. 72). Can you talk in lower tones through the can than through the air? What passes along the string?

108. Speed of Sound Waves.—We have, perhaps, seen a man strike a blow at a distance and waited some time before hearing the sound. This is because time is needed for the sound waves to travel through the air. Just as the ripples can be seen to move away from the spot where a pebble is dropped in still water, so the sound waves in air move away from a vibrating body at a speed which can be measured. This speed is a little greater in a warm than in a cold atmosphere. *Through air at ordinary temperatures sound waves travel about 1125 feet per second.* A mile would be covered in about five seconds.

Experiment 85.—Stand at some known distance (*e.g.* half a mile or more) from a steam whistle which is soon to be blown. Note the time when the "steam" appears (using a stop watch if possible), and see how many seconds pass before you hear the sound. Reduce the result to feet per second and compare with the rule.

Note other similar things—whistles on distant trains or boats, guns fired, blows struck, or engines puffing. Thunder is caused by lightning and both occur at the same instant. Could you tell how distant is the lightning by hearing its thunder? How would you do this?

109. Reflection; Echoes.—Roll a ball against a board; it bounds off at once. The ball is said to be reflected, and *the angle at which it leaves the board is the same as*

that at which it struck. Now roll it so as to strike exactly at right angles (as *cd* in Fig. 73 strikes *ab*), and the ball will be reflected so as to come straight back to your hand.

In just the same way *sound waves are reflected* from any building, hill, rock, or bank of woods which they strike. Usually these reflected waves pass off in a different direction; but when they strike squarely *at right angles*, they come back to their starting point and there produce a faint sound. This sound is called an *echo*. Because the waves have lost some energy in traveling, the echo is generally weak; if the air is too full of other sound waves, these weak echoes may not be heard.

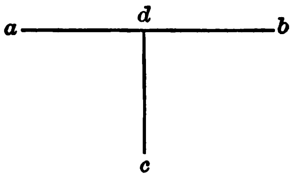

FIG. 73

110. Reverberation. — In a large empty hall sound waves may be reflected from wall to wall in many directions at the same time. The effect of this confusion of waves upon the ear is not a distinct echo, but rather a roar. Such an effect is called *reverberation.* It may be noticed in caves, wells, and other inclosed empty spaces.

111. Forced and Sympathetic Vibrations. — When a vibrating body touches another, *its motion* may start vibration in that other. In some cases this may be done also *by sound waves*, the waves in the air having enough energy to arouse vibration in certain bodies that they strike. This sort of vibration is of two kinds, — forced

and sympathetic. To understand the difference, it must be known that *every body has its own natural rate of vibration*, at which it vibrates when free to do so. When the motion of one body causes another to vibrate *at a rate which is not its own*, these vibrations are said to be *forced*. When the *natural rate* of the second is *the same* as that at which the first is vibrating, its vibration is said to be *sympathetic*.

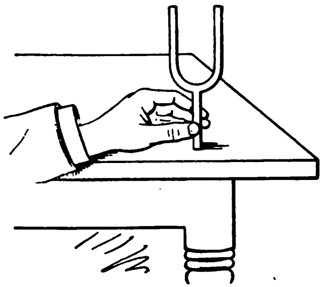

FIG. 74

Experiment 86. — Cause a tuning fork to vibrate. Can you easily hear its tone? Now strike it, and at once hold it to a table, as in Fig. 74. Is the sound any louder? The table is *forced* to vibrate by the motion of the fork.

Experiment 87. — Put water in a tall jar and hold a vibrating fork over it, as in Fig. 75. Vary the amount of water till the sound is the loudest. What body adds its vibrations to those of the fork? If the air column were in forced vibration, would its length make the difference that you now find? Is its vibration forced or sympathetic?

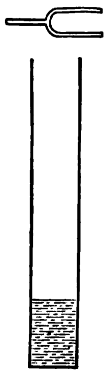

FIG. 75

112. Resonance. — In these experiments the sound seemed louder. The vibrations of the larger body were added to those of the fork, increasing the energy of the sound waves. In such cases the waves are said to be *reënforced*. The ability of a body to reënforce sound waves is called *resonance*, and the body itself is a *resonator*. Bodies of this sort are very useful and are employed particularly in musical instruments.

113. Resonators. — Thin boards, metal tubes, and columns of air are very commonly used as resonators.

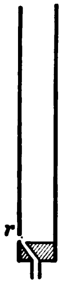

Fig. 76

Fig. 76 shows how organ pipes make use of *air columns* as resonators. Air entering an opening at the bottom strikes a *reed* at *r*, making it vibrate; this causes air in the pipe to vibrate, giving a loud tone. In the same way all *horns*, *cornets*, and other *wind instruments* are only tubes or pipes full of air; vibration is caused by the lips and a *mouthpiece*, but most of the sound waves come from the tube and the air within, which act as resonators. A *violin*, *guitar*, or *mandolin* would be useless without the thin wood body and the air it incloses, both of which reënforce the vibrations of the strings. *Pianos* have large *sounding boards* of thin wood which serve as resonators.

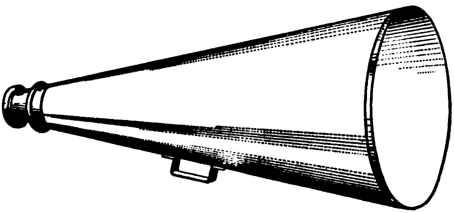

Fig. 77

Megaphones (Fig. 77) or speaking trumpets partly reflect the sound waves which would otherwise escape sidewise, and partly serve as resonators to increase the energy of the waves. By their use sounds may be heard at much greater distances from their sources than usual; sailors, firemen, and others find them very necessary.

QUESTIONS

1. Compare solids, liquids, and gases as media for transmitting sound waves. State any common examples which you have noticed, showing how some substances are better media than others.

2. How fast does a wave travel through air? How far would a wave go in one minute?

3. Explain the conditions necessary to produce an echo. Why is an echo generally heard better at night? Why better on water?

4. What is a reverberation? Why do we not hear much reverberation in a hall full of people?

5. How are forced and sympathetic vibrations caused? Explain the difference between them.

6. What is a resonator? How do resonators serve to make sounds seem louder?

7. Name different bodies which may act as resonators. Show the value of resonators in musical instruments, naming several instruments and the sort of resonator they use.

8. Explain the action of a megaphone. For what is it used?

SECTION III

DIFFERENT KINDS OF SOUNDS

114. Tones. — It must be kept in mind that the vibrations which cause sound waves are not only very small but usually very rapid — in some cases there are several thousand every second. Each of these vibrations causes one wave in the air, which moves away so fast as to be 1125 feet distant at the end of one second. But as the body keeps vibrating, and as each to-and-fro motion causes one wave, it is clear that at the end of one second the air from the body to a point 1125 feet away

in every direction will be full of sound waves (see Fig. 71). Others will follow these so long as the body vibrates.

Now when the vibration of the body is *simple*, every sound wave will be just like every other in length and form. The effect of these *regular waves* upon the ear is a pleasing sound called a *tone*. A tone may then be defined as *the effect upon the ear of a regular succession of like waves.*

115. Noises. — Almost no body does really vibrate in this regular manner, however. While a mass may move as a whole, many of its parts vibrate at a rate of their own. Thus, though each single part causes vibrations that are regular, many different sorts of sound waves may be caused by the different vibrating parts at the same time — some long and some short. The effect of these *many different kinds of waves striking the ear together* is a sound which we may call a *noise.* Note that the difference between tones and noises is not great. Almost no tones are strictly pure, but are mixed with a few weak waves that are not great enough to affect the sound seriously. A noise may be considered as simply a mixture of many tones.

116. Differences in Tones. — Tones may differ from each other in three ways — in *loudness*, *pitch*, and *quality.* Since noises are merely mixtures of many tones, the same fact is true of all sounds.

117. Loudness. — The *loudness* of a sound means the greatness of the *sensation.* This may depend upon several things. The *greatness of the original vibration* may

affect loudness, and this may depend upon the size of the vibrating body or the energy with which it moves. If the ear is at a greater *distance* from the source of the waves, the sound is less loud; the *kind of medium* through which the waves travel and the *direction of the wind* both have an effect upon the loudness of sounds. The *size of the receiver* is also an important factor; speaking tubes and ear trumpets (Fig. 78) serve to make sounds louder by collecting many waves. On a similar principle is the holding of the hand to the ear, as the aged often do.

FIG. 78

118. Pitch. — The *pitch* of a tone is commonly described by the words *high* or *low*, *shrill* or *deep*. We say that the pitch of a woman's voice is higher than a man's, or that a certain bell has a lower tone than another; and we know that whatever the pitch of a tone, it is quite different from loudness.

We have learned that sound waves vary greatly in length, some being long and others short; the vibrations of a simple pure tone, however, all have the same *wave length.* Now since all sound waves travel through the air at the same speed, the shorter the wave length, the more vibrations will pass a given point in a second. *The pitch of a tone depends upon how many vibrations reach the ear in a second; the greater the number, the higher the pitch.* Of course the length of a wave depends upon the vibrations in the body that caused it; so we may get some idea of the

source of a sound by noting its pitch. The vibrations of a small body are generally more rapid than in a larger body of the same sort, and the sound produced has a higher pitch.

119. Limiting Pitch. — Some waves are too long and some too short to affect the ear (§ 104). The limits within which waves may cause sound vary in different persons. Few can hear sounds lower than twenty vibrations per second, or higher than thirty thousand per second.

In music, *middle C* (C natural) has 264 vibrations per second; the octave above (high C) has twice as many (528), and the octave below has one half the number (132). A man's voice can rarely make a tone lower than 150 waves per second; while children may, in screaming, reach a pitch of several thousand vibrations.

120. Quality. — The first two features of sounds, pitch and loudness, are common in our experience and not hard to understand; the third, *quality*, may need a bit of thought. A piano and a violin may sound the same tone; it has the same pitch in each case, and may be sounded with equal loudness, yet we should have no trouble at all in telling the sound of a violin from that of a piano. The same would be true of tones made by a cornet, banjo, harmonica, harp, flute, or other instrument. Clearly there is some feature of tones, other than loudness or pitch, which seems to depend upon the instrument that produces them; this feature is called *quality*.

121. Quality explained. — Very few sounds are pure tones (§§ 114, 115); even those which are pleasing enough to be called *musical* contain a few weaker tones

besides the chief or *fundamental* tone. These weaker ones are called *overtones;* their effect is not great enough to make the sound unpleasant or to alter its pitch, but still their presence in the sound can be noticed by the ear. It is the effect of these overtones which gives to a sound its *quality.* And since the overtones may differ in different instruments, it is plain that one tone may be like another in pitch and loudness and still have a different quality.

122. Musical Sounds. — The sounds in *music* are usually tones that are nearly pure. They are made by different bodies in a state of nearly simple vibration; strings, air columns, metal plates and tubes, sheets of wood and skins, wires, and other devices are used. Sometimes the tones are made singly and often in groups, several being sounded at once. In such cases the tones are generally of such pitch that their waves cause a regular movement upon the ear, making a pleasing sound called a *chord.* A careless arrangement of tones may produce a jarring sound called a *discord.* A succession of chords is called *harmony.*

FIG. 79

123. The Voice. — The *voice* is caused by the vibration of the *vocal cords.* These are narrow strips or folds of membrane (*aa*) on either side of an opening, *b* (Fig. 79), leading to the lungs. Air passing through *b* causes the cords to vibrate.

The *pitch* of the voice is raised or lowered by drawing the cords more or less tightly; *loudness* depends upon the energy with which the air is driven out, and *quality* upon the shape and movements of the throat and mouth. *Speech* is made by movements of the lips, tongue, palate, teeth, and other parts of the air passages. We form words mainly by varying the *quality* of the voice; but among some nations, like the Chinese, pitch also is of importance in talking.

QUESTIONS

1. Define a tone. Explain the difference between a pure tone and a mixed noise.

2. In what ways may tones differ from each other?

3. What is meant by loudness? Upon what different conditions may it depend? Show how ear trumpets help to make sounds louder.

4. Name some familiar sounds that have a high pitch, and some having a low pitch. Upon what does pitch depend? How? Do short waves or long waves have the higher rate of vibration?

5. What is the lowest, and what the highest, number of vibrations per second that the ear generally can hear? How many vibrations per second has middle C?

6. Give an example of two tones differing only in quality. What determines the quality of a tone or sound? What is an overtone?

7. In music, what is a chord?

8. Explain how the voice is produced. How is the pitch of the voice varied? How do we vary its loudness and quality?

9. How is speech effected? Do dumb persons have a voice? Why can they not talk?

10. Name some different musical instruments. Classify each as a stringed instrument or a wind instrument, etc.

11. In stringed instruments what is the original vibrating body? Does this have to be reënforced in any way? Explain the use of the head of a banjo, the sounding board of a piano, or the body of a guitar. Why does a piano give louder sounds than a harp?

12. What effect upon the pitch of a tone do you produce by tightening the string that caused it? How does the length of a string affect its tone? Does a heavy or a light string generally give the deeper tone?

13. How does a violin player vary the pitch of his tones as he plays? How is a piano tuned?

14. What usually causes the vibrations in a wind instrument? How are the tones usually made louder? What is the use of so much tubing in a horn?

CHAPTER VI

LIGHT

SECTION I

NATURE OF LIGHT

124. What is Light? — We already know a few things about light, — that it may come from objects which are hot, that it travels through air and also through some solids and liquids, that it may travel very long distances, that it affects the eye so as to produce sight, and other facts. To the questions, What is light? and How does it travel? we can give only a partial answer.

125. Light Waves. — In the study of heat we learned that the sun and other heated bodies give off *radiations*, which may travel to a distance and there cause heat in some substances but not in some others. We also know that the sun may shine upon different bodies equally, making some appear light and others dark. And again, we have noticed that the sun may affect our skin to color it in summer, may cause cloth to fade and paper to become yellow, and may bring about other changes that are chemical in their nature. So we see that the sun's radiations may produce three different effects, — *heat*, *light*, and *chemical changes*.

Scientists think that these radiations (or rays) may be all of the same sort, differing only in wave length.

Different effects produced by them vary with their wave length and also with the substance upon which the rays fall. For convenience, however, those which produce heat in a body are called *heat radiations;* those which cause chemical changes, *actinic rays;* and *those which affect the eye* to produce sight are called *light waves.*

126. Luminous and Illuminated Bodies. — *All objects are seen by means of the light waves that pass from them to the eye.* These light waves may have their origin (starting point) in the body itself, or they may fall upon it from some outside source and then be directed to the eye from that object. Bodies which give out light waves from themselves are called *luminous;* those which give off only waves which have fallen upon them from some other source are said to be *illuminated.* The sun, lamp flames, glowing coals, the electric arc, and very hot iron are examples of luminous bodies — they are *sources* of light waves. Such bodies may be seen when no other source of light is present; whereas illuminated objects — chairs, tables, books, flowers, clothing, the earth, plants, animals, the moon, and many others — disappear from sight as soon as all sources of light waves are taken away.

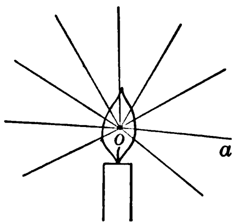

FIG. 80

127. Rays. — Light waves start from a *luminous point,* as *o* (Fig. 80), and extend in all directions in *straight lines.* The straight line marking the direction of any one wave is called a *ray, oa* (Fig. 80). Note that no wave ever goes in a curved path,

so long as the medium is constant; whenever the direction of a ray is changed, it is sharply broken at a point and passes on in a straight line until again changed.

128. The Ether. — Light waves travel long distances, as from the sun and far more distant stars, through *space* which we know to be rarer than any vacuum that man can make. Clearly no air is needed to carry these waves. Yet we must suppose that some *medium* is necessary, even though it may be very rare; therefore we speak of this medium just as if it were known to exist, and call it *the ether* (§ 93). The ether is supposed to fill all space, even entering the pores of solid matter. Light waves are then assumed to be *vibrations of the ether*, as sound waves are vibrations of the air.

129. Speed of Light Waves. — *Through space, light waves travel about 186,000 miles per second.* This speed is so great that for all distances through which we can see on earth, the waves travel instantly. A ray of light would pass entirely around the earth seven times in one second; and rays from the sun, 93,000,000 miles away, reach the earth in a little over eight minutes.

As with sound waves, the speed of light waves varies in different media. *In general, rays travel faster through a rare than through a dense medium.*

130. The Passage of Light Waves. — Some substances allow light waves to pass freely through them; glass, air, and water are examples. We can see through them clearly, and they are said to be *transparent.*

Other substances allow light waves to pass through, but scatter them in different directions; ground glass

and oiled paper are examples. Such bodies are called *translucent;* they let light through easily, but we cannot see objects through them.

Opaque bodies are those through which light waves will not pass at all. Wood, granite, iron, and brick are opaque. Since rays will not pass through an opaque substance, it is clear that those which fall upon it must either be taken into the body and stopped there, or be turned off from its surface. Waves taken in by a body are said to be *absorbed;* when they are turned off from its surface, they are said to be *reflected* (§ 109).

131. Shadows. — When an opaque body is placed so as to stop the waves that stream from a luminous source,

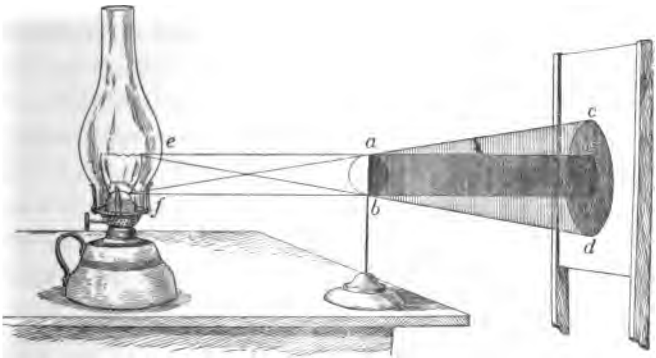

FIG. 81

it is said to cast a shadow. In other words, a *shadow* is a space from which light waves are excluded by some opaque mass. Whenever the luminous body is of sufficient size, there will be a lighter edge about a shadow,

in which the rays from some part of this luminous body may fall, — as the portions *acc'* and *bdd'* in Fig. 81. A dark central portion, as *ac'd'b* in Fig. 81, receives no rays at all; this is called the *umbra* of the shadow. The lighter portion, which receives some (but not all) of the rays from *fe*, is called the *penumbra.*

Darkness, on earth, is always due to shadows. Even the darkness of night is caused by our passing into the shadow of the earth. In daytime we do not find it dark within shadows of trees, buildings, or other objects; this is because sunlight is reflected into these spaces from air particles and other bodies all around them.

132. Reflection. — *When a light wave strikes any surface and is turned off from it, the wave is said to be reflected.* This is important. It is due to *reflection* that objects can be illuminated; that is, objects that are not luminous can be seen by means of the waves which fall upon them and are reflected to the eye.

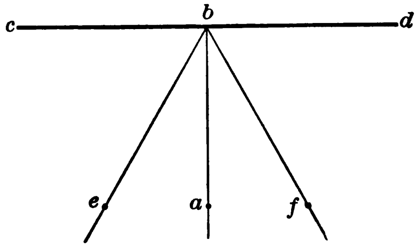

FIG. 82

Experiment 88. — Stand before a mirror, as at *a* (Fig. 82), holding a lighted candle in front of you. Rays from the candle strike the mirror *at right angles*, at *b*, and come *straight back* to you. Now move the flame to *f*. Find a point *e* from which your eye sees the reflection of the flame at *b*. Draw lines *fb* and *eb*; measure the angles *dbf* and *cbe*. How do they compare? Take a new point *f*, and repeat.

From this experiment we may learn the *Law of Reflection: The angle at which rays leave a surface is equal to that at which they strike it.*

Experiment 89. — Hold a small mirror before you, just below the eyes, about ten inches away, with its glass side facing away from you. In the other hand hold another mirror a few inches farther away, an inch or two higher than the first, and facing you. Look over the first into the second; with a little care these may be so placed that you will see several reflections of your eyes. This shows that reflected waves may be again reflected many times.

133. Reflection from Different Surfaces. — Light waves from the same source may fall upon different objects and there be so treated that the objects will present a variety of appearances to the eye. For example, rays from the sun may

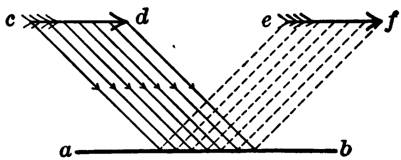

FIG. 83

fall upon several bodies: one of these may appear to be green, another red, a third may seem dark, and still another very bright. Yet they are all seen by means of rays which come from one source. These differences are due to the different behavior of substances toward light waves; many give off only a part of the waves that fall upon them, and their appearance to the eye depends upon what waves they give off.

But among surfaces which reflect nearly all of the rays that strike them, there is still a difference; some reflect regularly and others reflect only *scattered light waves.* When parallel rays from an object *cd* (Fig. 83) strike

a *smooth* surface *ab*, such as glass, still water, polished metals, etc., each ray is reflected at the same angle as all the others, and thus their positions among each other are unchanged. These reflected rays would form an *image* of the object, as *ef*. Fig. 84 may serve to show how such *rough* surfaces as snow, plaster walls, white cloth, etc., may reflect light waves which do not make images. Rays from the object $c'd'$ strike the rough surface $a'b'$; each ray is of course reflected from the point where it falls, so as to obey the law of reflection; but as these points lie in short lines of many directions, the rays will leave the surface $a'b'$ in various directions, forming no image.

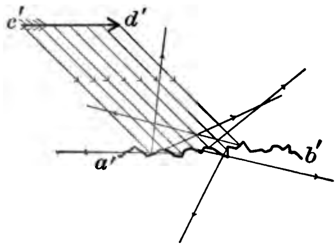

FIG. 84

134. Mirrors and Reflectors. — *Mirrors* are smooth surfaces which reflect nearly all of the light waves which fall upon them. *Plane* mirrors generally form *images* which are erect and like the object. Standing before a mirror, our image seems to be twice as far away as the distance to the mirror; in other words, the image appears just the same size as the object would appear if it were twice that distance away.

Rays striking a *curved* surface are reflected *as if they struck a plane* which touched the curve at that point only. Thus, in Fig. 85, parallel rays moving as shown by arrows are turned off from the curved surface just as if they had struck the straight lines back of the

curve. All rays parallel to these three would be similarly reflected to the point *f*; this is called the *principal focus* of the mirror.

Experiment 90. — Using a concave (in-curving) mirror, reflect the sun's rays to a focus. Hold a narrow strip of paper in front of the center of the mirror, and try to find this focus by moving the paper back and forth. When found, the focus will appear as a small spot of light, but very bright. Why is this spot so much brighter than is common in sunlight?

If now any luminous source be placed at the *focus* of a *concave* surface, those of its waves which strike the

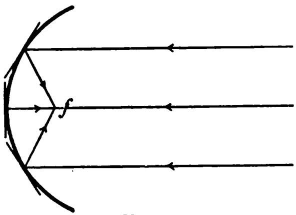

FIG. 85

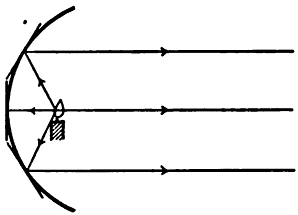

FIG. 86

surface will be reflected away *in parallel lines*, as in Fig. 86. Smooth curved surfaces used in this way are called *reflectors;* they are much used in locomotive headlights, search lights, and signal lights. They catch many rays that would be lost sidewise and back of a light, bending them all in the direction where they are needed.

135. Intensity of Illumination. — From a luminous source light waves move in straight lines in every direction. But it is evident that the rays, moving in straight lines away from a point, must be spread farther apart as the distance from the point increases. That is,

the total area covered by the radiations at any given distance from the luminous point is greater at a greater distance from the point. And as the same rays have to illuminate a greater area, it is clear that the *intensity* of the illumination cannot be as great. In other words, the farther a surface is removed from a luminous source, the less brightly it is illuminated.

Experiment 91. — Place before a lamp a large screen of wood or cardboard so that its surface will be 5 inches from the flame. At a point nearest the flame cut a hole one inch square in the screen. Now place another screen 5 inches beyond the first, so that the rays streaming through the hole will all strike this screen. Measure the illuminated spot and compare with the size of the opening. The second screen is now twice as far from the source of the rays as is the first. Move it to a point three times as far (*i.e.* 15 inches from the flame), and again four times as far. In each case measure the illuminated spot, compare with the opening, and note the brightness of the illumination. Make a general rule to apply.

QUESTIONS

1. What three different effects are produced by the radiations from the sun? What do we call these radiations when they affect the eye, causing sight?

2. Do any other bodies besides the sun give off light waves? What are such bodies called? Do other bodies than the sun give off heat radiations and actinic rays? State any examples to prove this.

3. How are we able to see such bodies as do not give out light waves of their own? What are such bodies called?

4. What is a light ray? What sort of a line do rays usually take? Can a wave travel in a curved path? How then can the sun's rays light a room into which they do not stream directly?

5. What is meant by the ether? Is it known to exist? How does it compare in density with any matter that we know?

6. How fast do light waves travel? How long time are the sun's rays in coming to earth? How does the speed of light waves vary with the density of the medium?

7. Define a transparent substance; a translucent substance; an opaque body. State examples of each. What may become of the waves that fall upon an opaque body?

8. What is a shadow? How is a shadow caused? Name the two portions of a shadow, explaining the difference.

9. Why is it dark at night? Why is it not entirely dark in the shade in daytime? Why is it not dark on cloudy days?

10. What is meant by reflection? State the Law of Reflection. Why do light waves from the same source make different impressions upon the eye when reflected from different things?

11. Explain the difference between reflection from smooth and from rough surfaces. What sort of surfaces reflect rays so as to form images? Give examples.

12. How are waves reflected from curved surfaces? What is the focus of a curved reflector? Explain the use of reflectors in obtaining a powerful illumination.

SECTION II

REFRACTION

136. Examples of Refraction. — We have learned that light waves travel usually in straight lines (§ 127), and also that the *direction* of these lines may be changed whenever a ray strikes a point and is reflected (§ 132). In another way the direction of a wave may be changed, — *when it passes from one medium to another that is denser or rarer.* Such a change of direction is called *refraction*, and the wave is said to be *refracted.*

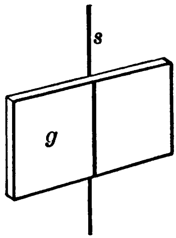

FIG. 87

Examples of refraction are common. A stick thrust into clear water often appears to be broken at the point where it enters the water. Objects often seem irregular when viewed through window glass, and the size of bodies may seem greater or less than real when seen through a lens. In such cases the changes are due only to the change in direction of the light rays in passing to the eye through different media.

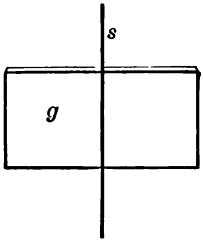

FIG. 88

Experiment 92. — Hold a piece of thick glass over a pencil so that a line from your eye to the glass meets its surface at an acute angle (less than a right angle). Does the pencil appear broken (Fig. 87)? Now hold the glass so that the line from your eye would meet its surface at right angles (Fig. 88). Does the pencil now appear to be broken?

Experiment 93. — Place a coin in the bottom of a dish of water (Fig. 89), looking at it as from *e*. The rays are refracted at *c*, so that the coin appears to be at *p*. Now look straight down

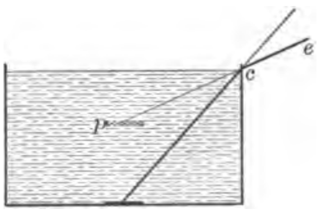

FIG. 89

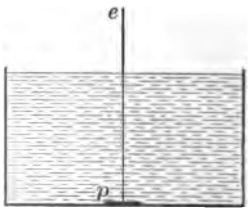

FIG. 90

upon it (Fig. 90), so that the rays *pe* meet the water surface at right angles. Are the rays refracted? Explain the reason for these results.

137. Refraction defined. — From these experiments we see that rays travel in straight lines through each

medium, and that they are bent only at the *point* where they pass from one to the other. Also we find that when the rays meet the surface between the media at right angles, they are not bent at all; the angle must be *acute* to cause refraction. Putting these facts together, we may say: *Refraction is the bending of light rays when they pass from one medium to another of different density, at an acute angle to the surface between the media.*

138. Cause of Refraction. — To understand refraction, it must be kept in mind that *light waves travel faster in a rare than in a dense medium.* In Fig. 91 let *abc* be the cross section of a prism of glass. Rays from an object (the arrow) move through the air with equal speed,

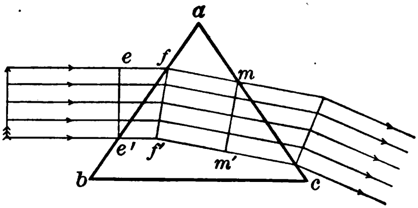

FIG. 91

so that when the first one reaches the glass at e' the others will all have reached the line $e'e$. Now since glass is denser than air, the first ray e' will move only to f', while e (still in air) moves to f; thus when e gets to f all the rays will have come to the line ff'. Through the glass they now move with equal speed, but *in a changed direction.* The first ray to leave the glass at m will now travel faster than those still within, so that when the last one leaves the glass at c, the direction of the waves will again be changed. Note that the waves are refracted *on entering and on leaving the prism,* and both times *toward its base.*

139. Lenses.— A *lens* is generally a piece of glass having one or both of its faces curved; its use is to refract light waves for different purposes. When the faces curve inward the lens is called *concave;* when they curve outward the lens is *convex.* Fig. 92 shows both shapes (in dark lines), and it also shows how each is like two prisms taken together. Look at each carefully until it is plain that parallel rays would *spread apart* after leaving a *concave* lens, and would *come together* after passing through a *convex* lens (Fig. 93).

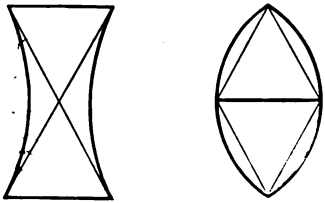

FIG. 92

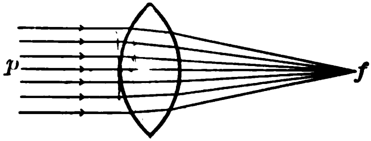

FIG. 93

Convex lenses are the more widely used. The general effect of convex lenses is to *converge* (bring together) the rays that pass through them. The point where such rays meet is called the *focus*, *f* (Fig. 93). When the rays entering the lens are *parallel* they all meet at one point, which is commonly called the *principal focus.*

FIG. 94

Experiment 94.—Using a convex lens, hold it so as to converge the sun's rays on a piece of paper (Fig. 94). Move the paper nearer or farther from the

glass till the rays all fall upon one small spot. What do you notice regarding this spot? If the lens were not in the way, how great an area would be covered by the rays that now fall here? Cause the spot to fall on tissue paper or a bit of gunpowder. Account for the intensity of the light and heat at this point.

140. How Images are formed.—When light waves are sent off from an object, *each point* sends off a separate set of rays which will be collected by a lens and refracted *to a separate focus.*

In Fig. 95 let *ab* be an object and *l* the lens. Now *every ray* sent out from a point *a* and passing through

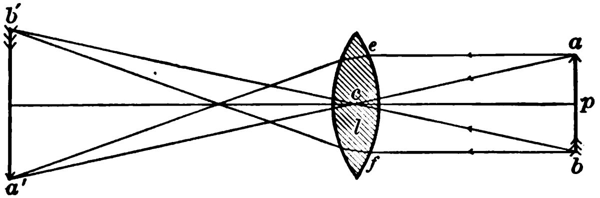

FIG. 95

l will be refracted to a focus *a'*; and every ray from *b* which is refracted, will come to a focus at *b'*. In the same way rays from all points in *ab* will be refracted to points between *a'* and *b'*. *Each focus will appear the same, and will have the same position among the others, as the point in the object from which its rays came.* Thus, if a screen be placed so that these foci (plural of focus) may be formed upon it, the *group of foci* together will form an *image* just like the object.

141. The Eye.—Just behind the dark opening in the eye is a lens,—the *crystalline lens.* This forms images on a screen called the *retina,* in the back part

of the eyeball. This retina is made of nerve fibers and endings, through which the image is reported to the brain.

Near sight is caused by too long an eyeball; the image is formed in front of the retina. *Concave glasses* may correct this fault; they spread the rays, making them come to a focus farther back. *Far sight* is due to an eyeball that is too short; the image is formed behind the retina. *Convex glasses* will bring the image forward and correct the trouble.

142. The Photographic Camera. — The *camera* is a box into which no light can enter except through a *lens c* (Fig. 96). This lens is just far enough from a *sensitive plate a* so that the rays from an outside object will be brought to a focus on *a*, forming an image there. The plate is covered with a substance upon which the light acts, affecting each point according to the amount of light focused upon it. Later the plate is *developed* and *fixed* in a dark room, after which the *image* appears plainly.

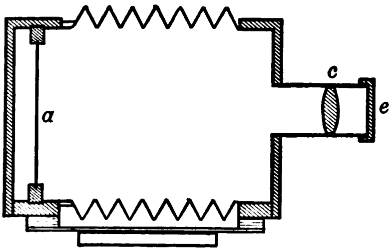

FIG. 96

143. The Microscope. — When an object is placed *nearer to a lens than its principal focus*, the rays that come from the object will spread apart after passing through the lens. Such rays then entering the eye make the object seem larger, or *magnified.*

A single convex lens used to magnify small bodies is called a *simple microscope.* A *compound microscope* is a group of several convex lenses in a tube, so placed that each magnifies the image formed by the one before it. With such an instrument objects may seem to be hundreds of times their real size.

144. The Telescope. — A *telescope* is a device for viewing distant bodies. It generally contains two convex lenses, — an *objective o* (Fig. 97), and an *eyepiece e.* The objective serves to collect as many rays as possible, and

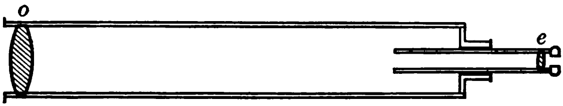

FIG. 97

the eyepiece magnifies the image formed by the objective. A few telescopes are enormous. One in the Yerkes Observatory, in Wisconsin, has an objective forty inches in diameter. Some of these can magnify images over five thousand times.

QUESTIONS

1. What is meant by refraction? State any examples of refraction that are familiar to you.

2. Name the conditions that are necessary in order that a wave may be refracted. At what point does refraction occur?

3. Explain the cause of refraction. Show why a wave is not refracted when it meets a surface at right angles.

4. What is a lens? How is a lens related to a prism in its effect upon light rays? Name the two general shapes of lenses.

5. What, in general, is the effect of a concave lens upon parallel rays? of a convex lens?

6. What is a focus? What is the principal focus? Can there be more than one focus formed through a lens? Can more than one principal focus be formed?

7. Explain, by a diagram, how images are formed through a convex lens.

8. Briefly show how images are formed in the eye. What is the cause of near sight and of far sight? How may each be remedied?

9. Describe the use of the photographic camera. How is it usually focused?

10. What is a microscope? How does a convex lens magnify images? What is a compound microscope?

11. State the use of a telescope. For what purpose are the larger ones made? Are spyglasses, field glasses, opera glasses, etc., microscopes or telescopes?

SECTION III

COLOR

145. What is Color? — We are so used to thinking of *color* as a part or property of any substance, that we may at first find it hard to understand that color is a property of *light waves*.

Experiment 95. — Examine colored pieces of paper in daylight; then in red, blue, or other colors of light. (This may be done by cutting a small opening in a wooden box and putting a lamp inside; red, blue, or other colored glass may be held over the opening. This should be done in a darkened room.) Now look at white paper in daylight, red light, etc. Does it always seem to be the same color? Examine pieces of dark cloth (dark blue, green, gray, etc.) in lamplight; mark each, and later look at them in daylight. Can you guess the color of each piece correctly by lamplight?

From these experiments we learn that the color of a body seems to change when differently colored waves

fall upon it. Also we know that any illuminated body is seen by means of such waves as fall upon it and are reflected to the eye. Thus it is clear that the color of any object depends upon what waves it sends to the eye, and that *color* itself is a property of the light waves.

Sound waves, we recall, vary greatly in their rate of vibration, and the resulting difference in sounds is called pitch. In the same way light waves differ greatly in rate of vibration; the effect of these different vibration rates upon the eye is that the waves have different colors. In other words, *the color of a light wave depends upon its rate of vibration.* For example, *red* waves have a *low* vibration rate, *green* a higher rate, while *violet* waves vibrate about twice as fast as red ones.

146. White Light. — Just as sound waves of many different vibration rates may travel together from a vibrating body to the ear, so light waves of many colors may mix together *in one beam* of light. The color of the *beam* as a whole might be very different from that of any single wave, just as the pitch of a noise is unlike that of any one tone in the noise.

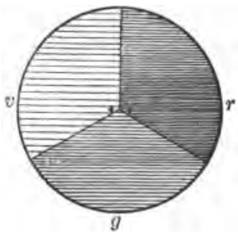

FIG. 98

Experiment 96. — Paste pieces of colored paper (violet, green, and red) on a circular cardboard, as in Fig. 98. Loop a stout string through the two holes near the center; twist this string so as to rotate the card rapidly (any boy knows how). What color does it seem to be while rotating? Do the same with other colors — two or more at a time.

The *sun* sends out waves of many different colors, so many that we do not know the number. These many-colored waves unite to form sunlight, which is commonly said to be *white light.* Thus white light is *a mixture of many colors.*

147. The Spectrum.—When light waves are refracted, those that have the *faster vibration rate* are bent *more* than those having the slower rate. Thus if a beam of light *ac* (Fig. 99), containing three colors,—red, green, and violet,—is refracted by a glass prism, the violet waves will be bent most, the green next, and the red least (§ 145). In this way the single beam *ac* is split up, its three colors of waves are *separated*, and *each falls on a different spot* on the screen *mn.* The appearance of the separated colors on *mn* is called a *spectrum.*

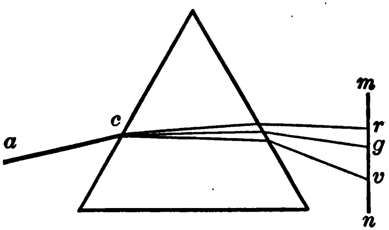

FIG. 99

Experiment 97.—Hold a glass prism (a cut-glass pendant or stopper) so as to refract sunlight. A spectrum will be formed, which may be seen somewhere about the room. Turn the prism till the spectrum falls upon a wall or any surface where it may be easily seen. This is the spectrum of white light (sunlight). How many colors can you count? Name them in order. Does each stop sharply, or gradually shade into those next to it?

The spectrum of *white light* shows *seven* distinct shades; these are called the *prismatic colors.* In order, they are *red, orange, yellow, green, greenish blue, blue,*

and violet. Note that these are not all of the many colors in white light, but only the more important groups.

148. The Rainbow. — After a shower, when the air still contains many heavy clouds, drops of water in these clouds may serve to refract the sunlight passing through them, and thus separate its several colors, like the prism in § 147. Thus there will appear reflected to the eye of an observer a spectrum which will contain the seven prismatic colors. This spectrum usually appears as an arc of a circle low down in the sky; it is called a *rainbow.*

149. Color of Light Waves. — Waves from a luminous source sometimes appear to change color after passing through a substance; a chimney of red glass seems to give a red color to the rays from a lamp, or sunlight seems blue after passing through blue glass. Now the fact is *not* that color is *given to* the waves, but rather that *some of the waves are taken from the beam of light.* Red glass, for example, contains a substance which *absorbs* (takes into itself) many of the waves that enter it, allowing the red rays to pass on through; in the same way, blue glass allows mostly the blue waves to pass through it. The sun often seems red at sunrise or in setting. This is because its waves have to pass such a long distance through the denser and dusty air near the earth that many of the shorter waves are absorbed, leaving mostly the red ones to pass entirely through.

150. Colors of Objects. — The *color of luminous objects* depends directly upon the color of the waves they send out.

Since *illuminated objects* are seen only by the waves that they *reflect* to the eye (§ 126), clearly the *color* of such bodies will depend upon (1) *the colors of waves that fall upon them*, and (2) *which of these waves they reflect.* When the light upon an illuminated object is *white light*, the object will appear *white* if *all* the waves are *reflected;* if none of the waves are reflected from the object, but *all are absorbed*, it is said to be *black;* if *all* the waves *pass through* a body, being neither reflected nor absorbed, the substance is called *colorless.* In the great number of *colored* objects, however, part of the waves are absorbed while others are reflected; the *color* of such substances depends upon the color of *the waves that are reflected.*

QUESTIONS

1. Is color a property of objects or of light waves? Why do different objects seem to be of different colors?

2. Upon what does the color of a light wave depend? Do waves of different colors ever unite in one beam? What is white light?

3. What is a spectrum? Explain how a spectrum is formed when light waves pass through a prism.

4. How many distinct colors in the spectrum of white light? Name them in order. Which has the fastest and which the slowest vibration rate?

5. What is a rainbow? How is a rainbow formed? When and where do rainbows generally appear?

6. Explain why light waves seem to change color on passing through certain substances. Why does the sun often appear red at sunset? Why is this more often true in hot, dry weather?

7. Upon what two factors may the color of an object depend? In sunlight, what objects appear white? black? colorless? What objects seem red? green? blue?

8. Is black a color? How are black objects perceived?

CHAPTER VII

ELECTRICITY

SECTION I

THE NATURE OF ELECTRICITY

151. Electrical Energy. — The question, What is electricity? has never been fully answered. Many things have been learned about its behavior, but with all their study men have never been able to discover what it is. For convenience we often speak of currents of "electricity," charges of "electricity," etc., as though it were a form of matter; but though we may do this, it must be borne in mind that we do not know anything which proves it beyond a doubt.

While men have been seeking to learn the nature of electricity, however, they have discovered many things which enable us to make it very useful. Particularly important is the fact that it possesses energy which may be made to do work for us when it is properly controlled. In this study we shall consider not so much the nature of electricity as the means by which *electrical energy* may be made useful to man. We shall seek to learn something about electrical energy along three general lines, — how it can be produced, how it may be controlled, and what are its effects. The study of these matters will doubtless show us much that is of interest as well as of importance.

152. How Electrical Energy is produced. — We have learned that in order to produce any sort of energy we must transform some other kind of energy into the desired sort (§ 98). In general we may say that the kinds of energy commonly transformed into electrical energy are heat, chemical energy, and mechanical energy. Electrical energy seems also to be developed upon certain bodies by friction, by simple contact, and by dipping into certain liquids. For common uses, the devices for producing electricity are usually the voltaic cell or the dynamo. These will be explained in a later section.

153. How Electrical Energy is controlled. — Electrical energy is easily controlled because electricity passes readily through some substances and not through others. *A body through which electricity passes easily* is called a *conductor;* one through which it passes *with great difficulty*, or not at all, is called an *insulator*. It must be clear that if a conductor is surrounded by an insulator, electricity may be kept within the conductor and made to travel long distances sometimes. This gives a partial idea of how electrical energy is controlled; a fuller explanation of conductors and insulators is made in § 157.

Among the better *conductors* are *metals* (copper, zinc, iron, etc.), *water*, *animal bodies*, *the earth*, and others. Of *insulators*, *dry air* is one of the best; more than any other substance, perhaps, it keeps electricity from spreading about where it would only be lost and might do injury. Other insulators are *wood*, *cloth*, *rubber*, and *glass*.

154. Electrical Effects. — The effects produced by electrical energy may be divided into four classes, — electrolytic, physiological, thermal, and magnetic effects.

Briefly, the *electrolytic effect* is that, when an electric current is passed through certain compound substances, it will break up the compound into the simpler substances that compose it. This process is useful in chemistry; it is used also in electroplating and electrotyping.

The *physiological effects* are those produced by electric action upon living bodies — usually animals. Heavy currents of electricity may kill animal life; weaker currents are sometimes used in treating certain diseases.

Thermal effects are those in which electricity causes *heat*. The wire through which a strong current is passing may become very hot, as seen in small electric lamps. Electric heaters and furnaces also depend upon this effect.

Perhaps most important of all is the *magnetic effect*. Wherever electrical energy is used to cause motion — in motors, cars, elevators, call bells, telegraph and telephone systems, signals, etc. — force is applied by means of magnets; and these, of course, make use of the magnetic effect of electricity.

155. Potential. — In describing the electrical condition of a body the word *potential* is used in somewhat the same way as the word *temperature* is used to describe its condition of heat. As a body may have a high or low temperature, so the potential of a body is said to be high or low; and as heat passes from a body of

high temperature to one whose temperature is lower, so electricity may pass from a point having high potential to a point of lower potential.

The potential of two points is described as high and low, or positive (+) and negative (–); and this means that their electrical condition is such that electricity would tend to pass from one to the other. The one from which electricity would pass is called *positive* and the one to which it would pass is said to be *negative.* This means only that the potential of the first is higher than that of the second, without regard to any fixed standard.

156. Electro-Motive Force (E.M.F.).— Different substances vary in the ease with which they carry electricity, but even the best of conductors offer some *resistance* to the electric current passing through them. To overcome this resistance a certain sort of electrical "pressure" is required; and this is furnished by a *difference in potential* between two points in the conductor. If one point has a high potential and another point has a lower potential, a current may be caused to flow from the first point toward the second. This may perhaps be better understood if we compare it with the flow of heat from a body of high temperature to another of lower temperature.

The difference in potential between two points in a conductor, which causes the current to flow and to overcome resistance, is called the *electro-motive force* of the current. The greater the difference between the potentials of two points, the greater is the electro-motive

force of the current in the conductor that connects them, and the greater is the ability of this current to flow against resistance.

QUESTIONS

1. Why is electricity important to man? What, in general, may be studied regarding electrical energy?
2. How is electrical energy made? What forms of energy are commonly used for the purpose?
3. What is a conductor? What is an insulator? Name examples of conductors and of insulators. Why should some insulators (as wood or cloth) become good conductors when wet?
4. Show the use of conductors and insulators in controlling electrical energy. What might happen if air were a good conductor?
5. Name the four general electric effects. Name uses to which each of these is put.
6. What is meant by potential? What is high potential and low potential? To what is potential somewhat similar?
7. By what means is a current kept up? Explain fully the meaning of electro-motive force. How can the electro-motive force of a current be increased and decreased?

SECTION II

STATIC ELECTRICITY

157. Electric Charges. — Some substances, such as glass, resin, silk and woolen cloth, when rubbed with other bodies of a similar nature, behave in a peculiar manner, as we may have noted. For example: a glass rod rubbed with silk cloth will pick up bits of paper; the dry hair sometimes seems drawn toward a rubber comb that is run through it, or seems inclined to "stand

on end" after being thus combed; sparks are sometimes seen to pass from fur to the hand that is rubbing it. In these cases both the body that is rubbed and the one that does the rubbing are said to be *electrified*, or *charged with electricity*, or to have upon them a *charge*.

Experiment 98. — Rub a glass rod with a silk cloth; at once bring the rod near small bits of paper. Quickly do the same thing with the cloth. Repeat the experiment, using a stick of sealing wax and a woolen cloth. Do you see evidence that any of these bodies are electrified?

In these cases the *charge* appears to be on the surface of the charged body, and only at the parts which were touched when the rubbing was done. This would be true when the substances used were glass, rubber, dry wood, silk, paper, sealing wax, sulphur, porcelain, or cloth. If certain other substances were used, such as the metals, the charge would appear not only at the part touched, but all over the surface of the body. Moreover, if this body, while still charged, were brought to touch another body which was like it in this respect, its charge would at once spread all over the other body as well. Thus it is clear that, in order to charge such a body, we should first separate it from other bodies by a substance of the sort first described,—cloth, glass, etc.

Substances of the first sort, over which the charge does not spread, are called insulators (§ 153). As has been said, dry air is one of the most important of these. Substances of the second sort are called conductors; all the metals, the earth, animal bodies, and water containing acids or salts are conductors. We have said (§ 153)

that electricity passes through a conductor; this way of speaking is in common use, but it should be noted that the charge is on the surface of the body and not actually within it.

We learn, then, that the electric charge upon a conductor moves rapidly and covers its whole surface, while that upon a "nonconductor" (insulator) remains at rest upon the part where it was developed. In this section we shall study the case of charged insulators,— where the charge is at rest, — and to this study we give the name *electrostatics*.

158. Positive and Negative Charges. — When bodies are electrified we find that their charges may be one or the other of two sorts, which seem to have certain different effects.

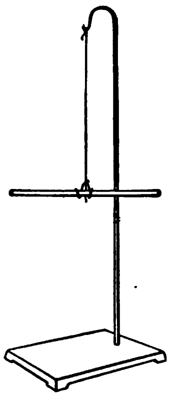

FIG. 100

Experiment 99. — Charge a glass rod by rubbing with silk, and hang it by a silk thread, as in Fig. 100. Using that part of the silk cloth which touched the rod, bring it near to one end of the latter as it hangs free to turn. Carefully note what happens. Now charge another glass rod in the same way, and bring its charged portion near that of the suspended rod. Note the result in this case. Is there anything in this experiment that would seem to show a difference between the electrification of the body that is rubbed and that of the one that does the rubbing? If you conclude that the glass and the silk are differently electrified, what would you say about the behavior of two unlike charges toward each other? Supposing the two rods to bear like charges, what do you learn about the behavior of two like charges toward each other?

These experiments show that when glass is charged by contact with silk, both the glass and the silk are electrified, but their charges are opposite in effect. It has been agreed to call the charge upon the glass *positive*, and the charge upon the silk *negative*.

The effect of these opposite charges upon each other is such that when the bodies bearing them are light and easily moved, these bodies will move toward each other; for example, the glass and the silk. But when two bodies bearing like charges are brought near each other, these charges act so as to push the bodies apart; for example, the two rods of glass. Many experiments may be made with small electrified bodies to prove the general law that *Like charges repel, and unlike charges attract, each other.*

The sort of electrification that any body receives varies according to its own nature and that of the substance with which it is rubbed. Thus, while glass may be positively electrified by rubbing with silk, it is negatively charged by flannel. Other conditions may also affect the sort of charge received.

159. Electrostatic Induction.—If a body that is not charged is brought near a charged body, and both are separated from the earth by insulators, the first shows signs of being electrified. In Fig. 101, let *a* be an electrified body and *b* an uncharged body; suspend them by silk strings and bring *b* near to *a*. The side of *b* that is nearer *a* will receive a charge of the opposite kind to that of *a*, while

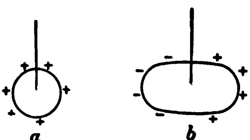

FIG. 101

the side farther from *a* will receive a charge of the same kind. The body *b* is said to be charged by *induction*, and the charges which it receives are called *induced charges*.

If a ball of pith be suspended by a silk thread, as in Fig. 102, it may be used in several experiments with electrified bodies. Charge a glass rod with silk and bring it near the pith ball; note how far the rod can be removed from the ball before the force ceases to make it move. Note also how readily the ball moves when the rod is near it. We may get from this an idea of the extent of the field of force about a body bearing even a small charge. The medium between the rod and the ball must be the seat of energy, and the ball moves so as to make this energy less. When the uncharged ball becomes charged by induction, the medium between the rod and the ball must be considered as in a state of strain.

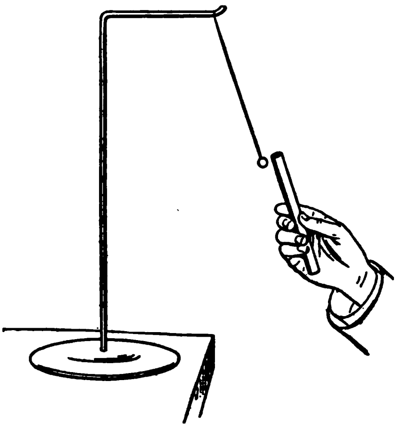

FIG. 102

160. Discharges. — Now if the body *b* is charged by induction from the electrified body *a* (Fig. 101), it is clear that these two charges bear some relation to each other. In other words, if there is no change in the positions of the two bodies, then a change in the potential of the

charge in *a* will cause a corresponding change in the charge of *b*. But since *a* induces a *negative* charge in the nearer portion of *b*, any change that makes the potential of *a* more positive will result in charging that portion of *b* still more negatively, — that is, even more unlike the charge in *a*.

Thus we see that a *difference in potential* (§ 156) exists between an inducing charge and the nearer portion of the charge that it induces; also that as the inducing charge becomes more intense this difference becomes greater. Now difference in potential gives rise to electro-motive force, which can overcome resistance; so when the difference between the potentials of the inducing charge and the induced charge is great enough to overcome the resistance of the insulator that separates these two charges, a spark passes between them. The path of this spark through air is a good conductor at that instant, and electricity passes from one charge to the other, making them of equal potential. This sudden and rapid flow of electricity is called a *discharge*. The sparks seen when a cat's fur is rubbed are caused by discharges between the fur and the hand.

161. Lightning. — *Lightning* is an electric discharge similar to that just explained, but on a far greater scale. The positively and negatively charged bodies are generally clouds, though in many cases the negative charge is on the earth. In some instances the positive charge is on the earth, the negative charge being in the clouds. The clouds are more commonly charged during the very rapid and heavy condensation

of vapor that causes sudden showers. These heavy rainfalls occur more often in the summer, so that lightning is more common at that season.

Lightning may be explained as follows. Suppose a positively charged cloud passes near the earth: buildings or the earth itself may become charged by induction, receiving a charge of the opposite kind from that of the cloud. If now the positive charge in the cloud increases in potential, the induced charge in the earth becomes more negative. This may go on until the difference in potential between the two charges is great enough to overcome the resistance of the air between them, and then a *discharge* takes place from one to the other. The passage of this discharge through the air produces electrical changes which cause the spark of flash.

Discharges may pass from clouds to the earth, or from the earth to a cloud; more often they go from one cloud to another. Objects through which the discharge passes are commonly said to be "struck." Tall buildings, towers, spires, trees, and the like are more in danger of being struck, because a charge induced on them is nearer the cloud. "Heat lightning" is the reflection of distant lightning. Thunder is the sound caused by waves of air set in vibration by the discharge.

QUESTIONS

1. How may a body become charged with electricity? Name some substances that can be charged in this way. Do they, in general, belong to the class of conductors or insulators?

2. What name is commonly given to the electricity in a charge of this sort? Why are not conductors easily charged in this way?

3. Name any cases of electrically charged bodies that are known to you. Experiment with a rubber comb and report the results.

4. What two sorts of charges are named? How do two bodies behave toward each other when similarly charged? How do they act when their charges are unlike?

5. What is meant by an induced charge? How is a charge induced from one body to another? Does the inducing charge lose some of its electricity in the process?

6. How does the induced charge compare with the inducing charge? State the condition of a charge induced in a body.

7. Explain the nature of an electric discharge. What must be the relation of two charges before a discharge can occur?

8. Compare the potentials of the two charges after the discharge. What generally attends a discharge? State any experience that you have had with discharges; any that you have seen or felt.

9. What is lightning? Between what bodies does it usually take place? When, in the year, is lightning most common? Why?

10. Fully explain the cause of the discharge. How long does it last? What objects are in most danger of being struck?

11. Explain the flash of lightning. What is thunder? Why is it not heard as soon as the flash is seen?

SECTION III

THE ELECTRIC CURRENT

162. The Voltaic Cell. — Most of the devices by which man employs electrical energy make use of what is called a *current*, that is, a stream of electricity passing along a conductor. This electric current is commonly produced in one of two ways, — by a dynamo or by a *voltaic cell.* In this section we shall consider the cell, which generally produces weaker currents than the dynamo.

Experiment 100. — Attach a piece of copper wire to a strip of zinc, and another piece to a strip of copper. Nearly fill a tumbler with water and pour into it a little sulphuric acid. Put the two metal strips into the water, being very careful that they do not touch each other at any point (Fig. 103). Now touch the ends of the wires together, as in the figure, hold the wire over a compass needle, and note any movement of the needle. This device is a simple cell, which may produce a weak current of electricity.

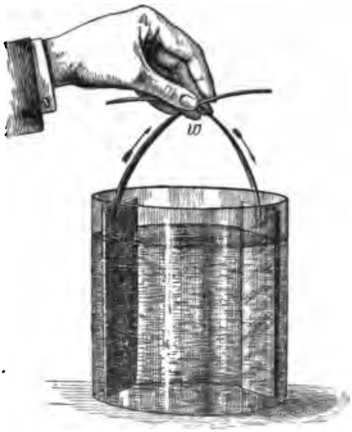

FIG. 103

A *cell* consists of two different solid conductors placed in any liquid conductor (except in a fused metal). It is found that when two such solid conductors are placed in such a liquid, they will be charged, but with a difference in the potential of each. If the solid bodies are of zinc and copper, as in Experiment 100, and the fluid is sulphuric acid in water, the potential of the copper strip will be higher than that of the zinc.

Now we have learned that the charge upon a conductor covers its whole surface, and spreads at once to any other conducting surface which touches it (§ 157). Thus if the two strips are not allowed to touch each other, and a wire of some conductor (copper) joins them outside the liquid, the charge on the copper strip (having the higher potential) will at once discharge along the conducting wire to the zinc strip, which has the lower

potential. This discharge along the wire is the electric current. The discharge would, of course, bring the two charges to the same potential; but the action of the liquid upon the two strips is such that it renews the *difference in potential* just as rapidly as the discharges are made. Thus the difference in potential is kept up and the current continues to pass along the wire.

The two metal strips are called *plates* or *poles;* the copper plate, having the higher potential, is said to be *positive*, while the zinc plate is called *negative*. Note that the plates must not be connected within the cell by any conductor except the liquid, nor outside the cell by any conductor but that through which it is intended the current shall flow. Otherwise all or a part of the current would be lost to useful work.

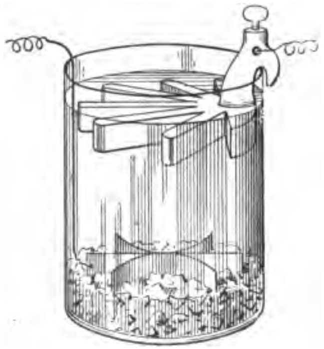

Fig. 104

163. Kinds of Cells. — Different substances may be used in cells, for poles or for liquids. For the poles, copper and zinc, or carbon and zinc are most commonly used. The liquid is generally water, in which some acid or salt has been dissolved. Sometimes the liquid is *a weak solution of sulphuric acid;* but as this destroys the zinc plate rapidly it is not often used in practice. More commonly the liquid is a solution of *sal ammoniac;* cells of this sort are used for ringing call bells and for light work; the

current is not very strong, but the cells serve for months sometimes.

On telegraphs and signal work, *gravity cells* are used (Fig. 104). The plates are *zinc* and *copper*, and the liquid is *a solution of copper sulphate* in water. Many cells have to be used in order to give a current of any strength, but they need little care except to be filled with water now and then. Many so-called "dry cells" are in use; these contain a liquid, but the outside covering (which usually forms the zinc plate) is sealed so that the liquid cannot get out.

164. The Circuit. — In order that a current may flow from the positive to the negative plate these must not

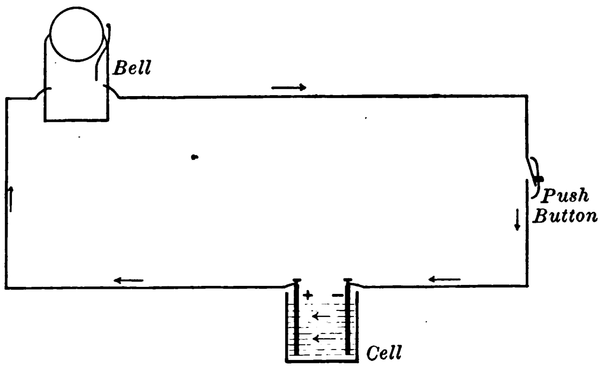

FIG. 105

only be connected by a conductor but there must be another conducting path back again to the starting point. In other words, there must be *a complete path of conductors* from the positive plate through wires or instruments to the negative, then through the liquid to

the positive again (Fig. 105). This complete conducting path is called the *circuit.*

If there is any break in a circuit at any point from beginning to end, no current will flow through any part of the circuit. This matter is of great importance to man in controlling electrical energy. For example, note in Fig. 105 that the circuit is not complete, being broken at the push button — for the weak current will not go through the air space. The circuit being broken at this one point, no current will go through any part of it, and the bell will not ring. But close the circuit by pressing the button, and the current travels at once through every part of the conducting path and rings the bell.

A completed circuit is said to be *closed*, or *made;* when interrupted at any point by an insulator, it is said to be *open*, or *broken.*

165. Resistance of the Circuit. — We have learned that any conductor offers some resistance to the passage of a current (§ 156). The resistance of a circuit is divided into two classes, — *internal*, or that offered by the cell; and *external*, or that of the wires, instruments, or other outside conductors. External resistance depends upon three things: the kind of substance, the length of conductor, and its area of cross section. Other things being equal, *the greater the length* of a conductor, or *the smaller its area of cross section, the more resistance* it offers to the current. Naturally a current traveling through a greater length of conductor would meet more resistance; and, lengths being equal, passage along a small conductor would, of course, be more difficult than over a larger.

166. Divided Circuits. — A main circuit may be tapped at different points by short branches (called *shunts*) which take the current to separate instruments. Each of these branches must of course join the main circuit at some point farther on, in order that the current may pass through it.

When a current is divided in this way, the *amount of current* that each branch gets depends upon its resistance: *the more resistance each branch offers, the less current flows through it.* This principle also is used in controlling electrical energy. For example, suppose it is desired to run a certain motor at different speeds: a device called a *rheostat* is put into the same shunt which runs to the motor. The rheostat contains several coils of wire, of different resistances, and a *switch* for making the current pass through one or more of these coils at will. The more coils the current is made to pass through, the greater the resistance offered by that shunt, and consequently the less current passes through it to the motor. Motormen on electric cars move a switch and control the speed of the car in this way.

167. Batteries. — A group of cells arranged on one circuit is called a *battery*. One cell does not furnish enough current to do very much work, so that the combined strength of two or more is generally used.

Cells may be combined in two ways, — in series or in parallel. In *parallel* arrangement all the positive plates are joined together and all the negatives likewise; the two sets are then connected by a wire. This arrangement *decreases internal resistance*, but gives no gain in

electro-motive force. When cells are arranged in *series*, the negative plate of each cell is joined to the positive plate of another; between any two cells the wires may lead away to some instrument (Fig. 106). Series arrangement is the more common; each cell added to a battery gives a gain of *electro-motive force.*

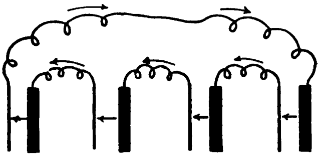

FIG. 106

168. Uses of Battery Currents. — Battery currents are not powerful enough to do heavy work. They are used for call bells, door openers, spark coils for firing explosives, electric signals, medical batteries, telegraph and telephone systems, and like purposes.

169. Electrical Measurements. — *Quantity of electricity* is expressed in terms of *coulombs*. *Current strength*, or greatness of current, is measured by *ampères*. The *electro-motive force* of a current is expressed in *volts*, while the *ohm* is the unit of *resistance*. Electrical *power*, or the rate of doing work, is measured by *watts*. One watt is the rate at which work is done when a current of one ampère flows between two points under a pressure of one volt. The value of a watt is about $\frac{1}{746}$ of a horse power (§ 68).

QUESTIONS

1. What is a cell? Tell how a cell may be made. Fully explain its action. What causes a current to flow from it?

2. What different elements are sometimes used in cells? What liquids? What sort of cell is used in telegraph systems, and why?

3. What is a circuit? If a circuit is broken at any point, what is the effect upon the current? Show the use of this in controlling electrical energy.

4. Distinguish internal and external resistance. Upon what does the resistance of a conductor depend, and how?

5. What is a shunt? When a current is divided, how much does each branch receive? Show how the supply of current to a motor may be controlled by using resistance.

6. What is a battery? In what two ways may cells be arranged? What is gained in each case?

7. Name some common uses of battery currents.

8. What is measured in units of coulombs? of ampères? of watts? of ohms? of volts?

9. Compare the value of one watt with one horse power.

SECTION IV

MAGNETISM

170. Magnets.—We have learned that one of the most important electrical effects is the magnetic effect, and that it is owing largely to this that electricity can be so generally used to cause motion (§ 154). When it is used to cause motion, the *magnetic force* is commonly applied by means of a magnet. A *magnet* may be described as a body which can attract iron. In other words, if a magnet is brought near a bit of iron, a force will act between them and cause them to move toward each other, if they are free to move.

Certain other substances may be attracted by magnets. A kind of iron ore found in the earth is one of these; also steel, cobalt, and nickel. Some substances are repelled (pushed away) by a magnet; for example, zinc and bismuth. It has been found that the nature of this

action (that is, whether the magnet shall attract or repel a body) varies according to the medium in which the magnet is held; a body which is attracted by a magnet, while both are in the air, may be repelled by it when they are in some other medium.

171. Magnetic Field. — The fact last stated (§ 170) shows that the magnetic force acts in the medium around the magnet. Simple experiments with a magnet and a compass needle will show that this force can act through considerable distances from the magnet. The whole space in which the magnetic force may be felt is called the *magnetic field.* Any magnet, then, is surrounded by a magnetic field, the different parts of which have varying intensities of force.

In describing this field we commonly speak of it as containing lines of magnetic force, or simply *lines of force.* In that portion of the field where the force is most intense the lines of force are most numerous; that is, there the lines are most densely crowded together. To get an idea of the arrangement of these so-called "lines of force," lay a piece of cardboard upon a magnet and sprinkle iron filings over the card. Try several different positions of the card upon the magnet.

172. How Magnets are made. — It is an easy matter to make a magnet of a piece of iron or steel. A body so treated is said to be *magnetized.* Two methods are generally used. The first method is simply to place the piece of iron or steel near a magnet, better in the more intense part of its field. (Compare this, but do not confuse it, with § 159.)

The other method depends upon an effect of electric currents, which may be shown by an experiment.

Experiment 101. — Pass a wire *ab* through a card, as in Fig. 107, and sprinkle iron filings on the card. Now send a strong current through the wire. Note any change in the filings; without disturbing the card, study their positions closely; stop the current, watching the filings carefully. Place a small compass *c* on the card and note any sign of a force acting.

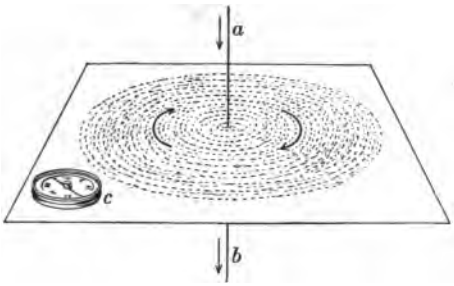

FIG. 107

This experiment shows that while a current is passing through a wire, the latter is surrounded by a field of force. If the wire is covered by an insulator and is coiled around a bar of iron or steel, this bar will be magnetized when a current is passed through the wire coil.

As a general rule, a piece of *soft iron* remains magnetized only so long as it is being acted upon by the force in the magnetic field; a piece of *steel*, however, remains a magnet for a long time after it is removed from the field.

173. Electro-Magnets. — A piece of soft iron wound about with a coil of insulated wire is called an *electro-magnet.* When a current flows through the wire it affects the particles of the iron in such a way as to make the whole bar a magnet. The intensity of such a magnet

may be greatly increased by winding several layers of the wire around the iron, like thread on a spool. Of course the wire must be insulated, for if it were bare the current would be conducted straight across the coil without going through its many turns.

Experiment 102. — Wind a piece of soft iron (*e.g.* a cut nail) with insulated wire, as in Fig. 108. Join one end of the wire to a battery, holding the other end in the hand so as to close and open the circuit at will. With the circuit open, touch one end of the nail to a common tack. Can you lift the tack in this way? Now close the circuit and try again. This device is a small electro-magnet. What is needed in order that it may exert magnetic force? Again opening the circuit, bring the end of the nail down to within one sixteenth of an inch from the tack lying on a desk; close the circuit, watching the tack. Lift the magnet and tack a few inches, and open the circuit. How long before the tack drops from the nail? How long a time is required for the soft iron nail to become magnetized, and to lose its magnetism?

FIG. 108

Electro-magnets may be made very powerful by increasing the number of turns in the wire coil and the strength of the current. Magnets of this sort are used in dynamos and electric motors. The use of soft iron for the *core* of an electro-magnet allows it to become magnetized almost instantly, and it is demagnetized (loses its magnetism) when the current ceases to flow (§ 172). For this reason electro-magnets are very useful in all electrical devices where motion is to be produced at will; for example, call bells, motors, signals, telegraph systems, etc.

174. Permanent Magnets. — We have learned that when a piece of *steel* is magnetized it remains a magnet after it is removed from the magnetic field. For this reason a magnet made of steel is called *permanent*. Of course there are many kinds of steel, and these vary greatly in their value as permanent magnets.

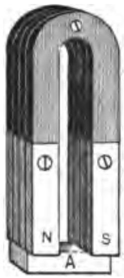

FIG. 109

Experiment 103. — Make an electro-magnet as in Experiment 102. Across one end of it draw a small piece of steel (a needle, knife blade, or steel pen) several times, *always in the same direction.* Try to pick up small tacks with this.

Two forms of permanent magnets are common, — the horseshoe (Fig. 109) and the bar magnet (a straight bar of steel). They are not made nearly as powerful as some electro-magnets are. Their use in small dynamos and in telephones is most important.

175. Magnetic Poles. — In using magnets we have perhaps noticed that the force seems to be greatest *at the ends*, while at the center none at all is felt. For this reason many magnets, both permanent and electro-magnets, are made in a horseshoe form, so as to bring the ends near together and exert greatest force at that point.


FIG. 110

Experiment 104. — Lay a bar magnet down upon a mass of iron filings; lift it carefully by the center. Notice the arrangement of the filings that cling to it (Fig. 110). Where are they most numerous? Where are they least in number? Does the number change gradually or sharply?

The ends of a magnet, or the points where its magnetic force seems greatest, are called its *poles*. In any magnet the two poles act differently toward other magnetized bodies, so they are separately named: one is called the *positive* (+) or *north* pole, and the other the *negative* (–) or *south* pole. Permanent magnets are usually marked by a line or groove across the positive pole; or the positive pole may be marked *N* and the negative *S*.

It must be noted that the steel or iron body is magnetized not only at its poles but throughout the body; the poles are simply the parts where the magnetic force acts with the greatest intensity. To show this more clearly, magnetize a steel needle, dip it in iron filings, and note its middle part. Now break it in the middle, dip one part in the filings, and note the end that was a portion of the middle before you broke it.

176. Law of Magnets. — Both poles of a magnet will attract a piece of iron that is not magnetized. Toward a magnetized body, however, the two poles act in an *opposite* manner.

Experiment 105. — The positive pole of a compass needle is the one that points northward. Secure a bar magnet whose poles are marked. Bring the positive pole of the bar near the + pole of the needle; note what happens. Now bring the same (+) pole of the bar near the negative end of the needle, while it is at rest, and make a note of the result here. Again, present the negative pole of the magnet to the negative end of the needle, noting this result. Finally bring the negative end of the bar to the positive pole of the compass needle, and observe.

What poles seem to attract each other, and what poles repel? Sum up your results in a statement of how the poles act.

Similar experiments with magnets give the same results. The facts may be stated briefly in a *Law of Magnets* as follows: *Like poles repel, and unlike poles attract, each other.*

177. Magnetism of the Earth. — A magnetized needle suspended so as to swing in a vertical plane ("up and down") is called a *dipping needle.* Fig. 111 shows five different positions of a dipping needle placed on a bar magnet. Note that at the negative pole of the bar the positive end of the needle is down; note its other positions with care, and if possible perform the experiment for yourself.

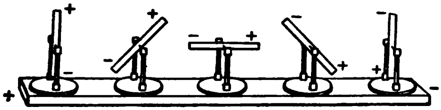

FIG. 111

Now it has been found that a dipping needle carried north or south along any meridian of the earth behaves in much the same way. This and other occurrences show that the earth is a great magnet, having its positive and negative poles like any magnetized body. These *magnetic poles* are two points on its surface, toward which the compass needle points. The *negative* magnetic pole is northwest of Hudson Bay, about 20° south of the north pole. Straight through the earth from this point, at a spot in the Antarctic Ocean about 20° north of the south pole, is the *positive* magnetic pole.

178. The Compass. — A magnetized strip of steel, finely balanced on a point so that it turns freely, will be so acted upon by the earth's magnetism that its positive pole will point toward the negative (northerly)

magnetic pole of the earth, and its negative end of course toward the positive magnetic pole. Such a magnetized bit of steel may be used as a *compass needle.* This needle is finely balanced, and usually swings over a card on which the "points of the compass" are marked (Fig. 112).

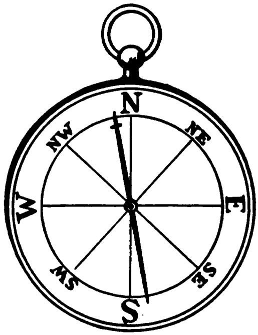

FIG. 112

The compass has long been a valuable aid to sailors and travelers, who often have little else to guide them. But owing to the position of the magnetic poles and variations in the earth's magnetism at different points, the needle points to the true north at only a few places on earth. To find the *true north*, the user of the compass has to know how far wrong the compass direction is at that point, and allow for it.

QUESTIONS

1. What is magnetic force? Define magnetism.

2. What is a magnet? Name two kinds of magnets.

3. How is an electro-magnet made? How is it magnetized? Why should the wire be insulated?

4. Name various uses of electro-magnets, showing why this form of magnet is particularly useful in each case. How may the power of an electro-magnet be increased?

5. Of what are permanent magnets made? How are they magnetized? Show any points of difference between permanent magnets and electro-magnets. Which form is most used in electrical devices, and why?

6. What are the poles of a magnet? How are they named? Why are magnets often made in horseshoe form?

7. State the Law of Magnets. How do both poles act toward unmagnetized iron?

8. Why does the compass needle point steadily in one direction? Where is the north magnetic pole? Is it positive or negative?

SECTION V

INDUCED CURRENTS

179. Induced Electro-Motive Force. — It has been found that currents can be produced by means of a magnet, and the electric currents so made are called *induced currents*. The very powerful currents now in common use are induced currents, and for this reason it is interesting to learn how they are produced.

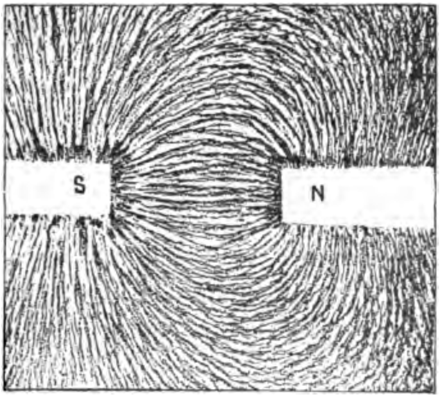

FIG. 113

Experiment 106. — Balance a thin card upon the two ends of a horseshoe magnet, and sprinkle iron filings evenly over the card. Note the positions taken by the filings.

The arrangement of the filings on the card shows the position of "lines of force" in the field between the poles of the magnet (Fig. 113). Now, if a circuit of wire be moved in such a magnetic field, a current will flow in this circuit *while there is a change in the number*

of lines of force cut by the circuit. In other words, so long as there is any *change* in the intensity of that part of the field which is within the circuit, an electro-motive force (§ 156) will be set up in the circuit; and this E. M. F. will vary according to the *rate of change* in the number of lines of force which fall within the area of the circuit. Of course it is at once clear that such induced currents will last but a moment, unless we can arrange to have the number of lines that fall within the area of the circuit continually changing. This can be done either by varying the intensity of the magnetic field, or moving the magnet, or by moving the wire circuit in the field. In practice the wire circuit is commonly made to rotate in the field, thus moving through a changing number of lines of force.

180. The Dynamo. — The *dynamo* is a device for producing induced currents. From what we have just learned it is evident that such a device must consist of a *magnet* and a *wire circuit*, together with some arrangement for varying the number of lines within the area of the circuit. The method in common use is to arrange the wire circuit on an axle so that it can be rotated within the magnetic field.

In the section of a dynamo, Fig. 114, *m* is the magnet; the space between its poles, *p* and *p′*, is crossed by lines of magnetic force. The coil of wire *a* (called the *armature*) is made to turn about an axle *e*, and in turning it cuts the lines of force. This sets up a current in the coil, which passes out through one *brush* *b* to the outside circuit *c*, supplying instruments on

the circuit, and back to the armature *a* through the other brush.

The energy by which the dynamo is run is usually furnished by a steam engine or water power. It is applied at the axle, being used to turn the armature. This turns at a high speed, the strength of the current generally increasing as its speed is raised.

181. Direction of the Current. — The whole circuit, outside and within the dynamo, is one continuous path,

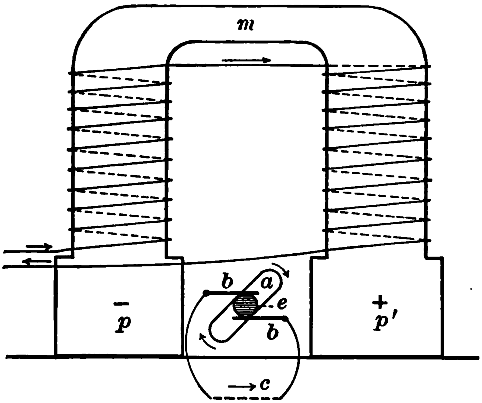

FIG. 114

the outside conducting wire being joined to that of the armature through the brushes *b*, *b* (Fig. 114). Now the *direction* of the current through this circuit depends upon the direction in which the armature *a* moves across the lines of force; and since each part of *a* cuts these lines in one direction during one half of a turn, and in the opposite direction the other half, the current will travel through the circuit *first in one direction and*

then in the other. Such a current is called an *alternating current.* The alternations, or changes of direction, occur with great rapidity.

Alternating currents may be used for some purposes, and their use is coming to be more important. For some uses, however, the current must be made to flow always in one direction. This is done by a simple device on the armature called a *commutator.* The current flowing steadily in one direction is called a *direct current.*

182. Kinds of Dynamos. — *Electro-magnets* are used in dynamos that are meant to furnish strong currents, because they can be made more powerful than permanent magnets. The current to supply the coils of these electro-magnets may be taken from the dynamo itself, or from a separate generator called an *exciter.*

FIG. 115

An exciter is a small dynamo, the magnets of which are permanent. Fig. 115 shows a *permanent-magnet* dynamo whose armature is turned by hand. Such devices are used in telephones to ring the call bell, and in a few other ways. Their current is not great, though stronger than the usual battery currents.

183. Uses of the Current. — Dynamo currents are used in motors, electric lights, furnaces, electric cars, electroplating and electrotyping, and for other purposes where powerful currents are needed. For lighting and

PLATE IV. AN ALTERNATING CURRENT DYNAMO

for the motors of some electric car systems alternating currents are employed. Direct currents are used in electrolysis, electroplating and electrotyping, for many motors, etc.

184. The Transformer. — The current that supplies small electric lamps in many houses and other buildings has to be of *high potential* (great electro-motive force) in order to travel through the long circuit. But such a current might prove dangerous if used freely in houses. To lessen the danger and still keep up the flow, a transformer is employed.

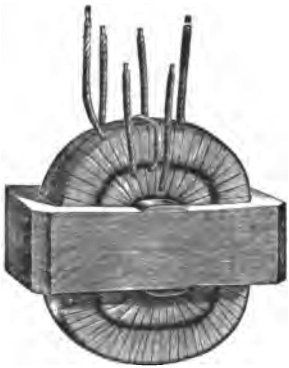

FIG. 116

A *transformer* consists of a coil of long, fine insulated wire, surrounded by a coil of short, coarse insulated wire (Fig. 116). The high-potential alternating current from the dynamo being passed through the long, fine wire coil, an alternating current is set up in the coarser wire by induction. This current has greater strength than that from the dynamo, but it has a *lower potential.* From the coarse wire coil, then, this low-potential current is led to the building where it is used. Because of its lower potential it is less dangerous.

For some purposes it may be desired to change a current of great strength but low potential into a current of less strength and high potential. To do this the

alternating current is sent through the coil of *coarse* wire; the current induced in the fine wire coil will have less strength but *higher potential* than the other.

185. The Induction Coil. — By means of this last-named principle, currents from batteries are often changed into currents of high potential. For this purpose an *induction coil* is used. The induction coil has two coils of wire, a fine and a coarse one as has the transformer, the battery current generally passing through the *coarse* wire *a* (Fig. 117).

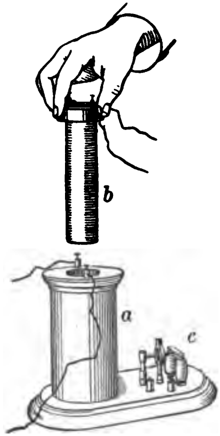

FIG. 117

This coil *a*, through which the battery current passes, is called the primary, and the other (in which a current is induced) is called the secondary coil. Of course the wire of the secondary coil cuts many of the lines in the magnetic field around the primary, and a current is induced in the secondary whenever there is any *change in the number of lines of force* that it cuts (§ 179). In the transformer this change is secured by using an alternating current; but since a battery gives a direct current, the induction coil must be so arranged as to produce the necessary change in some way. This is usually done by a *make-and-break piece c* (Fig. 117), which opens and closes the circuit very rapidly. The current thus rapidly flowing and stopping causes a change in the number of lines in the field surrounding

the coarse wire coil; a current is induced in the fine wire coil during each separate change. This induced current has high potential, and because the changes are so rapid the effect is nearly that of a constant (though not direct) flow. Coils of this sort are used in "medical batteries," Röntgen ray apparatus, wireless telegraphy, etc.

QUESTIONS

1. How, in general, are induced currents produced? How does the electro-motive force of these currents vary?

2. What is a dynamo? What are its important parts?

3. How is the energy for running a dynamo applied? In what part of the dynamo is the current produced? How is the current taken from the armature to the outside part of the circuit?

4. What is an alternating current? a direct current? Why should a dynamo current alternate? Can such a current be used? How is it changed to a direct current?

5. What advantage have electro-magnet dynamos over those using permanent magnets? What advantage have the latter over the former?

6. Name uses of currents from electro-magnet dynamos. For what are permanent-magnet dynamos used? How do the coils of the electro-magnets in a dynamo receive their current?

7. What is a transformer? Describe its structure. For what purposes are transformers used?

8. Through which coil in a transformer would you pass a current that was to be changed to a higher potential? to a lower potential? What sort of a current is used in either case?

9. Describe the induction coil. For what purpose is it generally used? Show how an induction coil may use a direct current, as the transformer uses an alternating current.

10. In which of the two coils is the current induced? State carefully the condition under which a current will be induced in this coil.

SECTION VI

USES OF ELECTRICAL ENERGY

186. Electric Motor. — The parts of an electric motor are the same as those of the dynamo (§ 180); in fact, an ordinary dynamo could be made to serve as a motor. The difference is that whereas the armature of a dynamo is turned by some outside means and a current is generated in it, *the armature of a motor receives a current* from some outside source and, being turned by its action, is able to impart *motion* to other bodies.

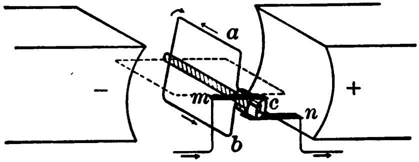

FIG. 118

Fig. 118 may serve to show the action of a motor. The *armature ab* is to turn about its axle, between the poles (+ and −) of the *magnet.* A current from a dynamo or battery enters through the brush *m*, travels around the armature coil *ab*, and out through *n*, as shown by arrows. Passing through it in this way, the current makes an electro-magnet of the armature, its negative pole being above and its positive pole below the horizontal position (dotted lines). That is, the part *a* becomes a − pole and the part *b* a + pole. Now since like poles repel and unlike attract each other, *a* is *repelled* by the − pole of the magnet and *attracted* by the + pole; also *b* is *repelled* by + and *attracted* by −. All of these forces tend to make the armature *turn about its axle* in the direction of the curved arrow. When it has turned so

that *a* is below and *b* above the horizontal position, a *commutator c* changes the direction of the current in the coil, so that *b* becomes the negative and *a* the positive pole of the armature. Thus the motion goes on always in the same direction.

Such a motor would use a direct current. Motors are now commonly made without commutators, to use an alternating current. These are often built upon the same frame as the dynamo which furnishes the current.

187. Electric Cars. — An electric car is driven by means of a *motor*. This is on the under side of the car

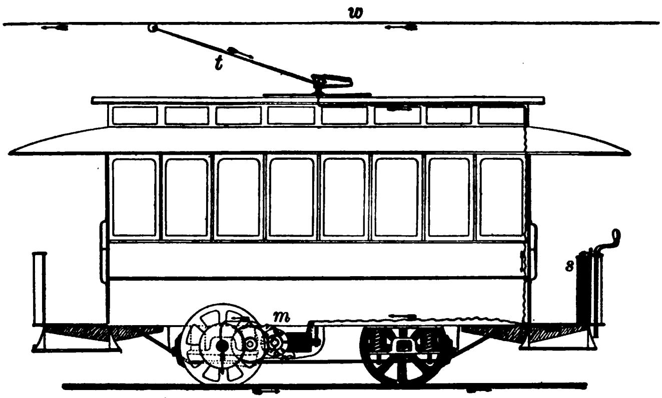

FIG. 119

m (Fig. 119); as its armature turns, the motion is transmitted to the wheels by a set of gear wheels (§ 72). The current is supplied from a wire *w*, or from a "third rail" beneath the car. After passing through the *controller s* to the motor, the current leaves through the wheels, traveling through the rails back to the dynamo.

The speed of the motor and car is governed by adding more or less resistance to the shunt at the controller *s* (§ 166).

188. The Telephone. — Only a very general explanation of the telephone can be given here. In Fig. 120, suppose some one talking at *A* to a person at *B*. The two instruments, at *A* and *B*, may be alike, though they usually differ in appearance. In each, *m* is a *permanent*

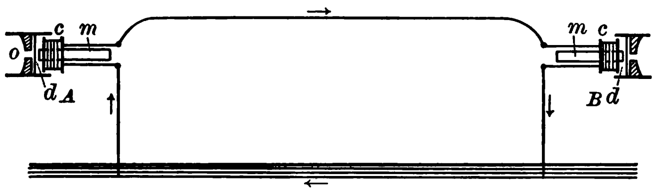

FIG. 120

magnet and *c* a *coil of wire* which is continuous with the circuit; *d* is a *disk* of thin iron.

As you talk before *o*, the sound waves cause the disk *d* to vibrate. The disk vibrating near the magnet *induces* alternate currents in the coil *c* — in one direction when *d* approaches *c* and in the opposite direction when *d* moves away. These currents go through the circuit to the coil *c* at *B*. Their effect is to strengthen and weaken the magnetic field acting upon *d* (at *B*), attracting and repelling *d*. In this way *the disk at B is made to vibrate just like that at A. Its vibrations cause weak sound waves* which may be heard by the ear at *B*.

Note that the *sound waves* are produced at *B*; alternate currents pass through the wire — not sound waves.

The circuit is completed by allowing the current to return through the earth. A battery is commonly used on the circuit to overcome the resistance of the wire.

189. The Telegraph. — The sender of a telegraph message uses a *key* *k* (Fig. 121), that simply closes and opens a circuit. In the distant office is a *sounder* *s*, by which the message is received. Pressing on *k* closes the circuit; the current then magnetizes the electromagnet *m*; this draws the armature *a* so that it strikes

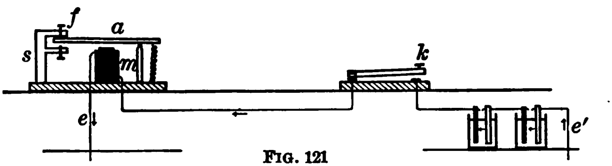

FIG. 121

the frame *f*, making a clicking sound. The key being lifted, *m* is demagnetized, and a spring pulls *a* till it strikes the frame above, making a different sound.

If these two sounds are separated by only an instant, a *dot* is said to be made; when a longer bit of time comes between them, the report is a *dash*. Every letter is represented by a different group of dots and dashes; the sender can make each at will, by pressing his key for a shorter or longer time. Any telegraph operator must learn to know each letter instantly by the sound of the dots and dashes which represent it. The current, as in the telephone, goes through one wire and returns to the battery through the earth (Fig. 121). As a rule, the batteries are composed of a few gravity cells placed at intervals along the circuit.

190. Electric Bells. — A common call bell is shown in Fig. 122. The hammer or striker is attached to a spring *s*; *m* is an electro-magnet. Follow the course of the current carefully. When the circuit is closed, *m* is magnetized and attracts the hammer; this moving quickly toward *m* strikes the bell once. But in so moving, *a* is also moved away from *c*, breaking the circuit at that point. At once *m* loses its magnetism and the spring *s* causes the hammer to move back again; but this also brings *a* again in contact with *c*. Thus again the circuit is closed, *m* is magnetized, the hammer hits the bell, and all is repeated. This happens very rapidly, producing the familiar buzzing sound of electric bells.

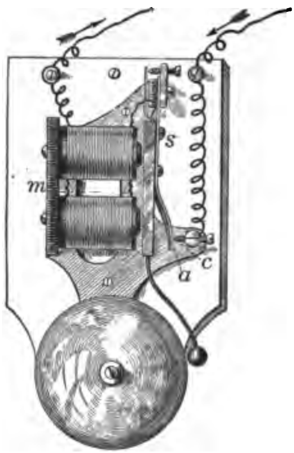

FIG. 122

191. Electroplating. — Articles covered with a thin layer of metal (gold, nickel, silver, etc.) are said to be plated. *Plating* is commonly done by use of the *electrolytic effect* of electrical energy (§ 154). The articles to be plated are hung in water that contains a *salt* (§ 213) of the metal to be used; a plate of the metal is also hung in the liquid. This plate and the articles are connected by separate wires with a dynamo or battery, in such a way that the current has to pass *through the liquid* (Fig. 123) *from the plate to the articles.* The

current, in passing through the water, acts upon the salt so as to set free the metal that it contains. This metal,

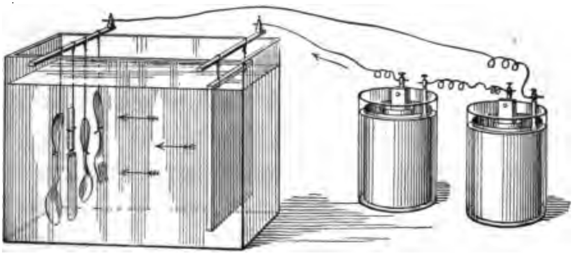

FIG. 123

in tiny particles, gathers about the solid bodies through which the current leaves the liquid, thus covering those articles with a metal coating. The current is commonly furnished by a dynamo, though a battery of cells may be used in experiments.

192. Electric Lights. — Electric lights depend upon the *thermal effect* of electrical energy. A current is made to pass through a poor conductor *against great resistance;* in doing this, it *heats the conductor until it is luminous.* Two sorts of lamps are common, — incandescent and arc lamps.

FIG. 124

Fig. 124 shows the familiar bulb of an *incandescent light.* The fine thread of carbon inside the bulb offers great resistance to the current that is sent through it. Thus the carbon thread becomes very hot and *luminous.* The space within the glass bulb is a nearly perfect

vacuum; if air were admitted, the hot carbon would quickly burn up.

In the *arc lamp* a current having very great electromotive force is made to pass through two carbon pencils placed end to end. Because these pencils just loosely touch each other, great resistance is offered to the current at that point. The current flowing against this resistance heats the ends of the pencils to white heat. Tiny bits of the carbon are detached from one pencil and pass, in a glowing condition, to the other pencil. Now the two points are drawn apart to a distance of about a quarter of an inch, the space between being filled with these glowing particles (Fig. 125). This space filled with the particles is called an *arc*, and the current is conducted through it. But the resistance is now even higher than at first; thus the two carbon points and the arc between are all very highly heated, so that they glow and give a bright light.

FIG. 125

Arc lamps are used in lighting streets, halls, and large rooms. They are arranged in series on the circuit

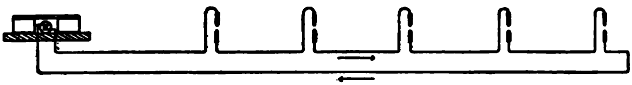

FIG. 126

(Fig. 126), and need a current of high potential. Each lamp contains a device for keeping the carbon points the proper distance apart as they are consumed.

193. Wireless Telegraphy. — Messages are now transmitted without wires over long distances by means of *waves in the ether*. These waves are caused when electrical discharges are produced. They travel with great speed in all directions from their source, growing weaker as they advance. Of course these waves can do no great work at a distance; but delicate instruments are made, by means of which *the weak waves serve to close the circuit* of a local battery and telegraph receiver, so that this receiver shall be operated by them.

QUESTIONS

1. Explain the action of the electric motor. What sort of current can be used? Name uses of electric motors.

2. How are electric cars driven? How is the speed of the motor and car controlled? How is the main circuit completed?

3. Explain the telephone. What travels over the wires? How are the sound waves that the listener receives produced?

4. How is a telegraph message sent by an operator? Describe the sounder on which it is received. Explain the action of the sounder.

5. Carefully explain the common electric bell.

6. What would you do with an article that you were going to plate? What is put into the water? What is the action of the current upon this substance?

7. Of what electrical effect do electric lights make use? Explain how a current is used to make a body luminous. What two sorts of electric lamps are common?

8. Explain the incandescent light. Why is the carbon thread placed in a vacuum?

9. Explain the arc light. What sort of a current is needed, and why? From what are the light waves sent out; that is, what parts of the lamp are luminous?

Part II. Chemistry

CHAPTER VIII

OUTLINE OF CHEMICAL STUDY

SECTION I

GENERAL INTRODUCTION

194. Chemistry. — Chemistry, like physics, treats of matter, but in a different way. Physics is the science of matter with regard to its motions, etc., whereas chemistry is the study of substances with regard to the *kind of matter* that is in them. For example, in physics we have found and studied several forces and their action, without much regard to the sort of matter acted upon, while in chemistry we shall be constantly dealing with kinds of matter, seeking to know what this or that substance is made of, how it may be made, how it may be destroyed, what can be made from it, and the like.

195. Chemical Changes. —Matter may of course be changed in many ways. The size, shape, or state of a body may be altered; it may be hardened, heated, or crystallized, etc. All such changes, which do not affect the substance or kind of matter of the body, are called *physical changes.* But when any substance is so acted

upon that there is some *change in the kind of matter*, a *chemical change* is said to take place.

Experiment 107. — Dissolve some common salt in water until no more can be taken up. Has any change occurred? Now boil the salt water to dryness. Does anything remain? Was this a physical or a chemical change?

Experiment 108. — Place a bit of sulphur in an old spoon and heat it over an alcohol lamp or gas burner. The sulphur melts and, if still heated, vaporizes. Hold a saucer just above the spoon; sulphur collects on the saucer in tiny particles. What sort of change?

Now burn a bit of sulphur in the spoon, holding the saucer above it as before. No sulphur collects on the dish. In burning, the sulphur unites with oxygen from the air, forming a different substance, that passes off as a gas. Is this a physical or a chemical change?

196. Composition and Decomposition. — In a general way, any chemical change falls under one of two classes, — composition and decomposition. *Composition* is the process of *uniting* two or more substances to form another. When a substance is *broken up* into the two or more substances that compose it, the process is called *decomposition*, and the body is said to be *decomposed*.

197. Kinds of Substances. — We do not need to be told that there is an almost countless number of different substances on earth. Many of these we know can be made from simple substances, by processes which man has devised. Others are found in the rock and soil of the earth, having been made by natural processes long ages ago. And a still larger number, perhaps, are made by the growth and action of living matter, — plant

and animal. These many kinds of substances may be considered in three different classes, — *elements*, *compounds*, and *mixtures*.

198. Elements. — Of this great number of substances there will of course be some that are composed of several simpler ones. These simpler ones may, in turn, be made of others that are still more simple. But clearly we cannot go on, without limit, breaking up each of these simple substances into simpler ones; that is, we must soon reach substances that are *perfectly simple* — that cannot be broken up into anything else. Such substances, *that cannot be divided into anything else*, are called *elements*. They are absolutely pure, each composed of only the one kind; the smallest particle of an element would be of just the same nature as a large mass of it.

Now with these facts clearly in mind, we shall easily see that elements cannot be made, as some substances are, by composition, since each is composed of itself only. The elements only *occur;* that is, they *are found* on earth, sometimes in a pure state but more often united with other elements. They may be separated from these other elements by different methods, called *analysis*.

Every substance, then, is made of elements; either of one alone or of two or more together. Nearly eighty elements have been discovered and named. Most of these are uncommon. Hardly a dozen occur in very large quantities. Of the common elements, *oxygen*, *hydrogen*, *nitrogen*, and *chlorine* are gases; *mercury* is the only familiar liquid; of solids, there are *carbon*, *sulphur*, *phosphorus*, and some *metals* (§ 212).

199. Compounds. — *When two or more elements unite with each other in a definite proportion*, the new substance formed is called a *chemical compound.* This will be explained more fully later (§§ 202, 203). Note, however, that the elements must be *united*, that is, not simply lying side by side in the same mass, but the smallest particles of each actually combined with those of the others. Also note that the result is a *new substance*, unlike either of the elements which compose it; even to its molecules, the compound is different from either of the elements.

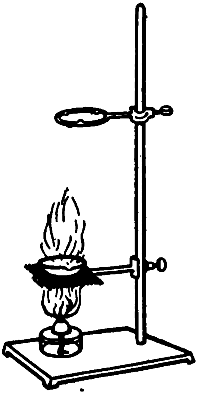

FIG. 127

Water is a chemical compound; its elements are hydrogen and oxygen — both gases. Other common compounds are *starch*, *sugar*, *alcohol*, *quartz*, and many *acids*, *bases*, and *salts*.

Experiment 109. — Put a small piece of zinc into a little hydrochloric acid (an inch in a test tube); note all that happens. If the zinc does not finally disappear, add more acid. When the zinc can no longer be seen, boil the liquid in an evaporating dish (Fig. 127) till dry. Examine the substance that remains. Do you think this a compound? Why?

200. Mixtures. — When two or more substances, *without uniting chemically*, together form another substance, that mass is called a *mixture.* A mixture may differ in some ways from each of the substances that compose it, but no new substance is formed; that is, *the mixture has no molecule of its own*, being composed of molecules of each substance lying side by side but not combined.

Mixtures are very common; many are made in nature and many are made by the work of man. *Wood* and *coal* are mixtures, also the *air*. Various sorts of vegetable and animal products — *cloth*, *paper*, *leather*, and many other mixtures — are common.

The difference between chemical compounds and mixtures is important. In *compounds* the elements unite to form a new substance, which has a molecule of its own; that is, all its molecules are like each other and like the mass. In a *mixture* the molecules are those of the elements or compounds that compose it; thus they are of different kinds, and the mixture, as a substance, has no molecule of its own. For further explanation see § 207.

Experiment 110. — Grind small quantities of sulphur and iron filings together in a mortar till well mixed. Draw a magnet through the mass. Is it a compound or a mixture?

QUESTIONS

1. Of what, in general, does the science of chemistry treat?

2. Show the difference between physical changes and chemical changes. Give examples of each. Does wood suffer a physical or a chemical change when burned?

3. What is meant by chemical composition? Define decomposition. Try to think of examples of each process.

4. What is meant by an element? How are elements generally obtained? How many have been discovered?

5. Are masses ever formed of one element alone? Name some common elements. With how many are you familiar?

6. What is a chemical compound? How does a compound mass differ from an elementary mass? Is the molecule of a compound the same in its nature as the mass?

7. What is a mixture? How do compounds differ from mixtures? Name some common substances that are mixtures.

SECTION II

CHEMICAL ACTION

201. The Atomic Theory.—The name *molecule* has been given to "the smallest particle of any substance that can exist alone" (§ 10). Now we have learned that elements combine to form compounds, and that each molecule of a compound is just like all the others. This would seem to show that each molecule must contain in itself a small portion of each of the elements in the compound. But this at once raises the question, How can a molecule (the smallest particle that can exist alone) be made up of *smaller parts?*

Scientists have answered the question by formulating an *atomic theory.* They say that there may be particles smaller than molecules, but that these can never exist alone, that is, *they must always be united with at least one other.* These smaller particles are called *atoms.* An atom may unite with others of its kind or of different kinds, but it must always be in a union.

A molecule, then, is said to be *composed of atoms.* Therefore we see that each molecule of a substance may be just like the others, and yet every one may be made up of atoms of different elements. In other words, when two or more elements unite to form a compound, the molecules of each element break up and the atoms of the different kinds unite with each other, forming molecules that will be all alike.

202. Chemical Affinity.—The atomic theory allows us still to say that the molecule is the smallest particle

of a substance that can exist alone. Clearly, a *compound* will no longer exist if its molecules are divided again, for each molecule is made of atoms of *different* elements. The molecules of an *element* are also the smallest bits that can exist alone, each molecule being made of atoms that cannot be separated unless by uniting with other different atoms. Between elements and compounds, however, there is this difference: the atoms of an element are just alike, and the same in substance as the molecule, whereas the molecule of a compound is made of different kinds of atoms.

In any molecule, *the force that binds the atoms together* is called *chemical affinity*. Its action in holding atoms together in molecules is somewhat similar to that of cohesion, which binds molecules together in masses. Without cohesion we should have no masses of definite form; without chemical affinity, no substances of *definite composition.*

203. Chemical Combination. — When two or more elements unite to form a compound they are said to *combine;* the process is called *chemical combination.* The number of atoms which may combine to form a molecule varies according to the substance formed; some molecules contain only two atoms, while others contain nearly one hundred. In any one substance, however, the *molecule* must always contain *the same number of atoms;* moreover, these atoms must always be those of the *same elements*, and each element must always be present with the same number of atoms. For example: water is a compound; a molecule of water must always

contain three atoms; two of these atoms must be those of the element hydrogen, and one atom must be of oxygen. If the two elements combined in any other proportion (say one atom of each), or if they combined with any other element, the molecule formed would not be that of water. Thus we may say that *chemical combination takes place only between definite proportions of certain elements.*

Every element does not by any means combine with every other element. Some elements may combine with several different ones, while others can unite directly with only two or three. The study of what elements combine with certain others is of course an important part of the chemist's work.

Sometimes the same elements may combine in more than one proportion. In such cases the resulting compounds would of course be different. For example, hydrogen and oxygen combine to form water (two atoms of hydrogen and one of oxygen), while if two atoms of oxygen unite with the two of hydrogen, a very different substance is formed. The three elements, carbon, hydrogen, and oxygen, combine in a great many different proportions, forming as many different compounds.

204. Decomposition. — When a compound is broken up into its elements it is said to be *decomposed.*

Naturally each element has a *stronger affinity* for some of the elements with which it may combine, than for others. Thus *in some compounds the elements will be more strongly united than in others.* Some compounds are so weak that they slowly decompose if simply left

to stand in air or in sunlight. Such compounds are called *unstable.* Strong compounds, which do not easily decompose, are said to be *stable.* Often when two or more compounds are mixed together, they so act as to decompose each other ; the atoms then unite with others for which they have greater affinity, and form new substances.

205. Heat assists Chemical Action. — *Heat* is a very important aid to chemical action, both composition and decomposition. Many changes which will not take place at ordinary temperatures easily occur if the substances are heated.

Experiment 111. — Into a clean, dry test tube put a little sugar ; heat gently. Notice what occurs, and when the mass becomes solid examine it. Has a chemical change occurred? In a similar way, treat some small bits of wood in a test tube, and examine. Can you discover whether heat has here caused composition or decomposition?

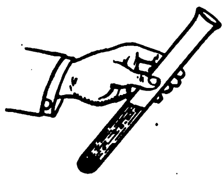

FIG. 128

Experiment 112. — Put a small piece of lead (a *BB* shot) into a test tube and add a *little* cold sulphuric acid (concentrated). Look for any action. Carefully heat the acid and look again for signs of action (Fig. 128). In this case the change includes decomposition and composition.

Combustion, or burning, is a very common sort of chemical action; and we know that to burn any common substance it must first be heated. Gunpowder and other explosives suffer rapid chemical change when heat is applied ; and in many other sorts of chemical action we find that heat plays an important part.

206. Heat from Chemical Action. — Not only does heat aid chemical action, but it is also given off during such activity. Some of the *chemical energy* set free during a chemical change is transformed into *heat*, and this is one of our important sources of heat (§ 74).

Experiment 113. — Put a small piece of zinc into a test tube with hydrochloric acid. Do you see any sign of chemical action? Grasp that part of the tube where the acid is. What further evidence of chemical action do you discover?

Experiment 114. — Cut a bit of metallic potassium the size of a small pea. Throw it upon water and stand away. The potassium decomposes the water, setting free its hydrogen and oxygen. Is this a chemical action? Do you note any sign that heat is given off during this action?

In *burning* a substance we have first to apply heat to it. The chemical action that is caused by this gives off enough energy itself to heat more of the mass; and so the combustion keeps on by its own heat, until stopped by some means.

207. Compounds and Mixtures. — We have seen that in a *compound* the molecules are all alike, and every one contains the same number of atoms of each element in the substance. That is, the molecules of each element have been broken up, their atoms *combining* with other atoms to form a new sort of molecule. *In a mixture no chemical combination takes place.* The *molecules* of each element or compound lie side by side in the mixed mass; each is unchanged and no new molecule is formed. The proportion of substances in a mixture is not definitely fixed, as in a compound, but the same ones may be mixed in any proportion whatever.

Experiment 115. — Grind a mixture of one half ounce of iron filings and one ounce of sulphur in a mortar. Examine carefully and draw a magnet through the mass. Is it a compound or a mixture still?

Into an old test tube put a little of the mass, and heat it slowly but well. When solid, allow the mass to cool. Break the tube and examine the substance. Is it iron? Is it sulphur? Is it a compound or a mixture?

208. Symbols. — For convenience, a system has been devised so that names of elements and compounds, and even chemical changes, may be expressed by *symbols.*

The *names of elements* are generally expressed by their first letter, or two letters: hydrogen, H; oxygen, O; carbon, C; calcium, Ca; zinc, Zn, etc. Moreover, the symbol for any element (*e.g.* C, O, or H) means also *one atom* of that element. To express more than one atom, a small figure is placed after the letter; thus H_2 means "two atoms of hydrogen"; O_3 means "three atoms of oxygen."

The symbol for a *compound* is made by writing the symbols of its elements in order, each showing the number of its atoms in the substance. Thus HCl means that in the compound *hydrochloric acid* one atom of hydrogen is combined with one of chlorine; HNO_3 (*nitric acid*) is a compound in which one atom of hydrogen, one of nitrogen, and three atoms of oxygen are combined.

The symbol of a compound (HCl, HNO_3, etc.) of course represents *one molecule* of the substance. Two molecules would be thus written, 2 HCl, 2 HNO_3, etc.; three molecules, 3 HCl, etc. The number (2, 3, etc.) so written belongs to the whole group of elements, and means that in the whole quantity represented the quantity of each element is taken just that number of times. For

example, $2HNO_3$ means "two molecules of nitric acid, each containing one atom of H, one of N, and three of O"; and it further means that in the whole quantity (two molecules) there are (2×1) two atoms of H, (2×1) two atoms of N, and (2×3) six atoms of O.

A list of the more common elements and their symbols follows. In cases where the symbol is quite unlike the word, it has generally been obtained from the Latin name of the element.

Aluminium	Al.	Gold	Au.	Oxygen	O.
Antimony	Sb.	Hydrogen	H.	Phosphorus	P.
Bismuth	Bi.	Iodine	I.	Platinum	Pt.
Boron	B.	Iron	Fe.	Potassium	K.
Bromine	Br.	Lead	Pb.	Silicon	Si.
Calcium	Ca.	Magnesium	Mg.	Silver	Ag.
Carbon	C.	Manganese	Mn.	Sodium	Na.
Chlorine	Cl.	Mercury	Hg.	Sulphur	S.
Copper	Cu.	Nickel	Ni.	Tin	Sn.
Fluorine	F.	Nitrogen	N.	Zinc	Zn.

QUESTIONS

1. Of what is a molecule composed? Can these particles exist alone? If a molecule is broken up, what becomes of its particles?

2. In what way do the molecules of an element differ from those of a compound? What is chemical affinity?

3. How many atoms may a molecule contain? Can two molecules of the same substance contain different numbers of atoms? Can the atoms in them be arranged in different proportions?

4. What is meant by chemical combination? When elements combine, can each then be seen in the compound? Can any element combine with every other element?

5. What is meant by decomposition of a compound?

6. State examples to show that heat assists chemical action.

7. Explain how heat may be given off during chemical changes. Show how the heat set free during combustion serves to keep up the burning.

8. Explain the difference between a compound and a mixture.

9. Tell everything about these substances that you can learn from their symbols: H_2O (water); H_2SO_4 (sulphuric acid); NaCl (common salt); $C_{12}H_{22}O_{11}$ (sugar); C_2H_5OH (alcohol).

SECTION III

CLASSES OF SUBSTANCES

209. Acid-Forming and Base-Forming Elements.—Two important classes of substances are *acids* and *bases*. Some elements have the power to unite with others to form acids, while different elements in a similar way usually form bases. *Elements that commonly form acids* are called acid-forming, or negative, elements; *those that form bases* are called base-forming, or positive, elements.

The common *negative* (acid-forming) elements are *bromine*, *carbon*, *chlorine*, *fluorine*, *iodine*, *nitrogen*, *oxygen*, *phosphorus*, *silicon*, and *sulphur*. Of *positive* (base-forming) elements there are *aluminium*, *calcium*, *copper*, *gold*, *iron*, *lead*, *mercury*, *nickel*, *platinum*, *potassium*, *radium*, *silver*, *sodium*, *tin*, and *zinc*. The element *hydrogen* seems to hold a neutral place, being found in both acids and bases.

Sometimes a *group of elements* acts like a single atom in combining with other elements; for example, NO_3 in nitric acid, or SO_4 in sulphuric acid. Such a group of elements is called a *radical*. Like elements, radicals are either positive or negative.

210. Acids. — An acid is a compound made up of *hydrogen* and a *negative element or radical.* Note these symbols of *acids:* HCl, *hydrochloric;* HBr, *hydrobromic;* HNO_3, *nitric;* H_2SO_4, *sulphuric.* Acids generally have a sharp or rather sour taste; they often act upon other compounds, causing chemical changes; some acids act strongly upon animal matter, and some are poisonous.

The sharp taste of many fruits is due to acids. Lemons, raspberries, and currants contain *citric acid;* grapes contain *tartaric acid;* apples and cherries, *malic acid.* Vinegar owes its sour taste to *acetic acid*, and sour milk contains *lactic acid.*

211. Bases. — A base is composed of OH in combination with a *positive element or radical.* OH is a negative radical; it is sometimes called *hydroxyl.*

Four *bases* are common: NaOH, *sodium hydrate;* KOH, *potassium hydrate;* $Ca(OH)_2$, *calcium hydrate;* NH_4OH, *ammonium hydrate.* The last of these, NH_4OH, is diluted with water and used for household purposes under the name *ammonia.* NaOH and KOH are used in making soap. $Ca(OH)_2$ is sometimes used in making other bases.

An *alkali* is a base that is soluble (can be dissolved) in water. The strongly basic compounds — NH_4OH, NaOH, and KOH — are alkalis.

212. Metals. — The positive or base-forming elements are commonly called *metals.* We usually think of a metal as a solid, heavy, and rather hard substance. These properties are true of some metals, but not of all;

for example, *mercury* is a liquid; *sodium* and *potassium* float upon water and are also soft. Thus it is difficult to find any common property by which to define a metal, and in this study we must be content to learn some of the important metallic elements, together with their general behavior.

By far the greater number of elements are metals. Some of these are very common on earth, while others are very rare. A few metals (*e.g. iron, copper*, and *zinc*) are of much importance in the life of man; but there are also several whose existence is never realized by us, and whose very names are never heard except among scientists.

A few metals are sometimes found free in the earth, though most of them occur only in compounds with other elements. Pure metals are obtained by breaking up the salts or the *ores* in which they occur. The following metallic elements are familiar: Al, Bi, Ca, Cu, Au, Fe, Pb, Hg, Ni, Pt, K, Ag, Na, Sn, Zn (§ 208). Of these, Ca, Na, and K are not common in a free (not combined) condition.

213. Salts. — The *salts* form a large and important group of substances. Many different salts may be formed by the action of *metals* upon *acids*, or of bases upon acids. In either case, *a salt is formed when the hydrogen of an acid is set free and some metal taken on in its place.*

Experiment 116. — To a little hydrochloric acid (HCl) in a test tube add a piece of zinc (Zn). Note the action. Bubbles show that a gas is given off; this is hydrogen (H). When the action ceases, boil the liquid to dryness. Describe the substance

that is left. Is it zinc? Is it hydrochloric acid? Is it a new substance? Name the three elements that you had in the test tube at first. Which one of these escaped? What ones have united? The substance is a salt — zinc chloride.

Repeat the experiment, using HNO_3 and Hg; again, using H_2SO_4 and Cu. What elements combine in each case?

Salts are named usually from the metals and the acids that compose them. For example, salts of H_2SO_4 (sulphuric acid) are called *sulphates:* Cu and H_2SO_4 form $CuSO_4$, copper sulphate; Fe and H_2SO_4 form $FeSO_4$, iron sulphate; Zn and H_2SO_4 form $ZnSO_4$, zinc sulphate; etc. Salts of HNO_3 (nitric acid) are called *nitrates:* $NaNO_3$, sodium nitrate; KNO_3, potassium nitrate; $AgNO_3$, silver nitrate; etc. Salts of HCl are called *chlorides:* NaCl, sodium chloride; KCl, potassium chloride; $CaCl_2$, calcium chloride; $HgCl_2$, mercuric chloride; etc. Not only metals but *positive radicals* may unite with acids to form salts. The positive radical NH_4 (ammonium) forms two common salts, — NH_4Cl, ammonium chloride (sal ammoniac), and NH_4NO_3, ammonium nitrate.

Since there are many different acids and metals, the *number* of different metallic salts is great. Some of these occur in the earth; NaCl (common salt) is very abundant, also KNO_3 (saltpeter) and $NaNO_3$. Many salts can be prepared by man, and in some cases they are prepared by him in great quantities.

The *uses* of salts are also numerous. Some are useful as foods, notably chlorides and phosphates; very many are used in medicine, — chlorides, bromides, phosphates, sulphates, nitrates, carbonates, etc.; others are used as

sources from which to obtain acids or metals. Salts are used in many mechanic arts, in photography, in electroplating, electrotyping, and batteries; in plaster, in fertilizers, in explosives, and in other ways.

214. Oxides. — Nearly all elements combine directly with *oxygen* (O); that is, each forms with O a compound in which itself and oxygen are the only elements. The compound formed by the direct union of an element with oxygen is commonly called an *oxide.*

Some oxides are solids and are very hard, some are gases, and still others are liquids. They occur very often as powders, — that is, masses of small particles. Iron rust is an *oxide of iron;* lead scraped bright and then exposed to the air becomes covered with a thin, dull coating of *lead oxide.* An oxide of carbon, CO_2, is a gas; it is found mixed with the air, and is formed whenever C burns in O.

Similarly, *sulphur* (S) combines directly with some elements to form *sulphides.* Of these, iron sulphide (FeS_2) is very common; Cu, Pb, Sn, and Ag also form common sulphides.

215. Minerals. — The earth, so far as we can discover, is composed largely of rock masses (and soil on the surface) which are either pure *minerals* or mixtures of minerals. Mineral substances are compounds, — commonly oxides, carbonates, or sulphates. The *oxide of silicon,* SiO_2, is very common — we call it *quartz;* other oxides are those of Al, Ca, Mg, K, Na, and Fe. The important carbonate is that of calcium, $CaCO_3$, called *limestone;* and the sulphate of calcium, $CaSO_4$ (*gypsum*), is also common.

216. Ores. — Most of the metals are found in the earth in the form of ores. An *ore* is a mineral substance containing a metal that may be removed from it for man's use. The mineral substance may be any sort of rock mass. The metal itself is mixed with the rock, sometimes in its *free* (or uncombined) state, but more often as an *oxide*, a *sulphide*, or a *salt*. That is, if we were to see an ore of some metal, we should see a rock in which were scattered masses of possibly the pure metal itself, but more likely of some salt, oxide, or sulphide of the metal. Iron, copper, tin, lead, silver, gold, zinc, and a few other metals are taken from ores.

217. Alloys. — An *alloy* is a mixture of two or more metals, made by melting them together. Many alloys may at first thought seem to be metals; they are not elements, however, but are made by man's work. *Brass* is an alloy of copper and zinc; *bronze* is made of tin and copper; *solder* contains tin and lead; *gun metal* and *bell metal* contain copper and tin in different proportions. *German silver* is an alloy of copper, zinc, and nickel; *type metal* contains lead and antimony; and *pewter* is an alloy of lead and tin.

218. Hydrocarbons. — An *hydrocarbon* is a compound of *hydrogen* and *carbon*. There are many hydrocarbons, for these elements unite in various ratios. Two common hydrocarbons may serve as examples: acetylene (C_2H_2), a common illuminant used in automobile headlights; and marsh gas (CH_4), the explosive "fire damp" of coal mines. Kerosene and other petroleum products contain hydrocarbons.

219. Carbohydrates.—A very important group of compounds can be made from the elements *carbon*, *hydrogen*, and *oxygen*. They are made in nature, chiefly by the activity of plants. Because of their composition (C and H_2O) they are called *carbohydrates*. *Starch*, *sugars*, and *cellulose* are common carbohydrates; they occur in seeds, all parts of living plants, and fruits. The carbohydrates form a very important part of the food of most animals.

220. Proteids. — Another group of substances that are necessary to the life of higher animals is called *proteids*. These contain the elements *carbon*, *hydrogen*, *oxygen*, and *nitrogen;* sometimes sulphur or phosphorus also. Proteids occur in the white of eggs, in lean meat, cheese, wheat flour (gluten), gelatin, etc.

221. Solutions. — When a substance is dissolved in a liquid it is said to be in solution. The liquid in which a substance is dissolved is called a *solvent*. Certain solids, liquids, or gases may be thus put in solution; their molecules are separated and they mix with those of the solvent. This mixture of a substance in a solvent is called a *solution*. There is, of course, a limit to the amount of any given substance that a liquid can dissolve. When the solvent holds in solution all that it can dissolve of any substance, the solution is said to be *saturated*. In the case of solids, dissolving is hastened if the solvent be heated. It is well known that some substances dissolve better in hot water than in cold. Stirring or shaking assists solution by mixing the particles more rapidly. A substance that can be dissolved in a liquid is said to be *soluble*.

Experiment 117. — Dissolve the following substances in equal volumes of water: common salt, sugar, sal ammoniac, ammonium nitrate, magnesium sulphate, and calcium sulphate. Note how much of each can be dissolved in the water. Which are the more soluble?

Which of these substances are soluble in water: HCl, oil, alcohol, kerosene, molasses, mercury, and NH_4OH?

Experiment 118. — Into two equal volumes of water put equal quantities of sugar. Stir one and allow the other to stand quietly. Which dissolves more rapidly?

Again try to dissolve two equal quantities of sugar in equal volumes of water, one cold and the other heated. Try to dissolve some lead chloride ($PbCl_2$) in cold water in a test tube; now heat the water (Fig. 129) and note the result. Does heating help in dissolving solids?

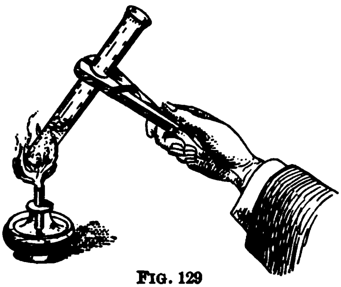

FIG. 129

Some substances are much more soluble than others, when put into the same liquid; and many that will not mix with one solvent will dissolve in another. Of the solvents, *water* is the most common and important. Many salts, acids, and bases are soluble in it, besides some other substances. For this reason water is widely used as a cleansing agent. *Alcohol* is also a common solvent; *tinctures* and *essences* are solutions of different things in alcohol, and its use in medicines is important. Many of the fats and oils are soluble in the *alkalis*, such as NH_4OH, NaOH, and KOH. *Mercury* dissolves several of the metals, forming *amalgams*. *Ether*, *turpentine*, and *carbon disulphide* are also used as solvents for certain substances.

QUESTIONS

1. What class of elements are commonly called negative? What are positive elements? Name some elements in each class. What is a radical? Name two radicals.

2. Define an acid. What properties do acids generally possess? Name any acids that you can. Name any substances that you think may contain an acid.

3. What is a base? Name four common bases. For what are these sometimes used? What is an alkali?

4. Name several metals. Are they elements, compounds, or mixtures? How are the metals generally obtained?

5. Under what conditions is a salt formed? Name any salts that you can. Are salts very numerous? Are they important?

6. In what ways are salts obtained? Name uses of salts.

7. What is an oxide? Name any oxides that you know of.

8. What sort of substances compose minerals? Are minerals compounds or mixtures?

9. What is an ore? Does the metal in an ore occur in a free state or combined with other elements? Name metals that are obtained from ores.

10. What is an alloy? Name some common alloys.

11. Name the elements that compose hydrocarbons. Name any common hydrocarbons.

12. What elements combine to form carbohydrates? Name any such compounds, telling where they commonly occur.

13. What is a solution? Is it a compound or a mixture? Name some common solvents. What is a soluble substance?

14. When is a solution saturated? What condition in the solvent may assist the dissolving? Of what use are proteids?

15. What sort of substance is a tincture? What is an essence? What is an amalgam?

16. Name the class of substances to which each of the following belongs: iron; copper sulphate; sugar; mercury; kerosene; common salt; gelatin; household ammonia; starch; iron rust; lead; brass; gasoline.

CHAPTER IX

COMMON SUBSTANCES

SECTION I

ELEMENTS

222. Oxygen. — *Oxygen* is a gas without color or odor; it occurs most widely of all the elements. Many salts and acids, and all bases, carbohydrates, and oxides contain O. It is also a very important element in water, air, and the solid earth. In the air oxygen is *free* (not combined with other elements), and it serves two great purposes — it *supports combustion* (burning) and *helps to support animal life*. We see its importance at once when we know that without O in the air animals could not live and common fires would not burn.

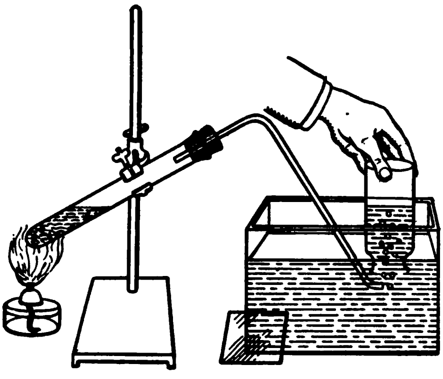

FIG. 130

Experiment 119. — Fit a stopper to a large test tube. Perforate the stopper with a round file and push through this hole one end of a glass tube, bent as in Fig. 130. Hang the whole on a

ring stand, so that the other end of the tube shall dip below the surface of water in a large vessel (see Fig. 130). Into the tube put 5 grams of potassium chlorate ($KClO_3$) mixed with 5 grams of manganese dioxide (MnO_2). Stop the tube tightly and heat it. Bubbles of gas soon appear in the water. Now fill two or three pint jars with water; tip one bottom upward under water and hold it over the tube so that the gas shall go up into it. Be sure that the jar is full of water at the start, and allow no air to enter it. As the gas flows, the water in the jar is pushed down and out. When the jar is full of gas (*i.e.* the water is all out of it), cover it with a piece of stiff cardboard or glass and lift it from the water. In the same way fill two other jars, and keep each covered (Fig. 131). The gas is O. By heating, $KClO_3$ is decomposed into KCl and 3 O.

FIG. 131

Experiment 120. — Into one jar of O put a glowing splinter of wood. In another hold a bit of burning sulphur (Fig. 132). In the third place a lighted bit of candle. Be careful to keep the jars covered as much of the time as possible. In each case what do you notice when the burning substance is first put into the jar? What do you notice after it has burned a few moments? Try to explain this.

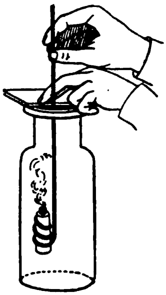

FIG. 132

These substances seem to burn better in the jar of pure O than in the air. In either case the *burning is a process of chemical combination*, the substance combining with *oxygen;* in the jar the O is nearly pure, while in the air it is mixed with a much larger quantity of another gas (N), so that the bodies burn better in the jar. Note carefully that when substances burn in air (*e.g.* wood, kerosene, paper, etc.), it

is because some of their elements are uniting with the O of the air. It is for this reason that a draught of air is necessary in stoves, lamps, and various fires.

223. Hydrogen. — *Hydrogen* also is a colorless and odorless gas. It is an important element, forming a part of all acids and of water. Animal and vegetable substances contain large quantities of H, but it is not common in its free state. The element may be separated from acids by the action of metals upon them (§ 213). Hydrogen is the *lightest substance* known, being $14\frac{1}{2}$ times lighter than air. Balloons are usually filled with it, so as to make them rise in the air.

Experiment 121. — Arrange the apparatus the same as for making O (Experiment 119), filling jars with water. Into the test tube put 5 grams of zinc with 5 cubic centimeters (cc.) each of water and HCl, but do not heat. After the gas has flowed a few seconds, collect some in jars by the same method as in Experiment 119. This gas is H. $2\ HCl + Zn = ZnCl_2 + 2\ H$.

Experiment 122. — Uncover one jar of H, at once holding a lighted match near the opening. *Always be careful with H*, for it burns in air and explodes if mixed with it. Using a small jar, partly uncover it for an instant; then cover it again and shake it once. Now apply a match to the opened jar, being careful not to get the face too near. If the air and H are mixed, a slight explosion may occur. Does H burn in the air? Does it kindle easily? With what element does it combine?

Hydrogen combines with O very easily if it be heated to its kindling temperature; once lighted, it burns readily. Pure H burning in pure O makes a very hot flame. It is the H in many substances, such as kerosene, paraffin (candles), wood, paper, etc., that makes them kindle easily.

224. Nitrogen.—Like H and O, *nitrogen* is a colorless and odorless gas. It occurs free in the air, nearly four fifths of the air being N. In combination with O (*i.e.* NO_3) it forms a part of those salts that are called *nitrates*, and it is a factor in the proteids, which occur mostly in animal matter. N is not an active element, and it does not support combustion. Owing to this last fact, N in the air serves a very great use by checking fires; that is, if a larger portion of the air were O, fires would burn more fiercely and they could not be controlled so easily.

225. Carbon.—The element *carbon* is a solid. Several substances are nearly pure C; for example, charcoal, coke, lampblack, boneblack, and gas carbon. Coal also contains a large amount of carbon. Notice that each of these substances is one that *remains* after some compound has been broken up; for example, charcoal is left when wood is burned imperfectly, lampblack when oils are burned without a good supply of air, etc. This shows that C occurs in compounds which may be broken up by heat. The gases in the compounds are first driven off, leaving the C. If plenty of air be supplied and the heat be great enough, C will combine with O (*i.e.* will burn) and pass off as a gas, CO_2 (*carbon dioxide*).

Experiment 123. — Burn a match (wooden) in air, allowing it to burn completely. How much ash remains? Now break up the wood of a match or a splinter into bits, place these in a test tube, cover with a little dry sand, and heat over a flame. Do you see any evidence of decomposition? What remains in the tube? Explain the difference between this result and that from the burning in air. Similarly, heat some sugar in a test tube till it is solid. Note and explain the result.

Carbon occurs very commonly in *living matter*, particularly in vegetable substances. In these cases it is nearly always combined with other elements, usually O and H. The element occurs free in two forms, diamond and graphite. *Diamond* is the hardest of minerals, and *graphite* one of the softest; both are crystalline, and each is nearly pure C. Graphite mixed with clay is used as "black lead" in pencils.

226. Sulphur. — *Sulphur* is a solid element, brittle, and of a yellow color. It occurs free in the earth, especially near volcanoes; it also occurs combined with metals in sulphides and sulphates. It burns easily, forming with O a gas, *sulphur dioxide* (SO_2). The compounds of sulphur (*e.g.* FeS_2, H_2SO_4, H_2S, etc.) are of great importance to man. In its free state, S is used in preparing matches, gunpowder, and rubber goods; also in medicine. *Sulphuric acid* (H_2SO_4) is one of the most important of chemical compounds.

227. Phosphorus. — *Phosphorus* is a solid element, slightly yellow in color, and of a waxy nature at usual temperatures. It is an acid-forming element and occurs largely in *phosphates*. P is very active, combining with several elements directly and at low degrees of heat. It should always be kept and cut under water.

Experiment 124. — Cut a piece of P no larger than half a small pea. Dry this on blotting paper and place it in an evaporating dish. Place a bit of iodine so as to touch the P. Do you notice anything that is unusual?

Caution. Do not touch P with the hands, and do not breathe the fumes from burning P. The substance is very poisonous. Also be careful never to leave the least bit lying around.

Combination of P with O also takes place very easily. Sometimes P will burn as soon as it is placed in the air, especially if it be cut or rubbed a little. Owing to the ease with which it kindles, P is commonly used in making *matches*. The red tip contains some P mixed with other substances. Simple rubbing heats this tip enough to make the P burn, and this kindles the wood. P gives out a faint glow in the dark; hence it is used in luminous paint, etc.

228. Chlorine. — *Chlorine* is a greenish-yellow gas having a disagreeable odor. It is not common in a free state,

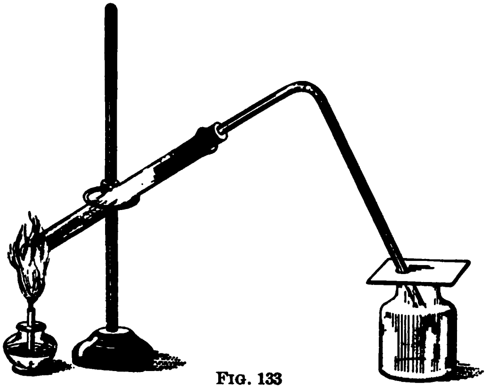

FIG. 133

but occurs in a group of salts called *chlorides*. With hydrogen Cl forms *hydrochloric acid*, HCl. The pure element acts strongly upon the throat and lungs if inhaled. It is used as a disinfectant and as a bleaching agent.

Experiment 125. — Arrange apparatus as in Fig. 133, passing the tube to the bottom of a jar through a loosely fitting cover of cardboard. Into the test tube put 5 g. of MnO_2 and 10 cc. of

HCl. Heat the mixture. Cl gas is set free and flows into the jar, driving out the lighter air. *Do not breathe any of this gas.* Note the color of Cl. This is one of the few gases that have color and can be *seen*. (If Cl is accidentally inhaled, pour alcohol on a cloth and breathe through the cloth for a few moments.)

Experiment 126. — When the gas in the jar is very yellow, remove the flame, wait a half minute, then remove the glass tube from the jar, keeping the jar covered. Now moisten a small piece of colored calico, drop it into the Cl, and quickly cover the jar again. If no change is noticed soon, try another piece of a different color.

A substance called *bleaching powder* is much used in bleaching cloth and paper, because it contains Cl.

229. Iron. — *Iron* is the most important of metallic elements in man's work. Its uses are too common to need mention here. The element occurs in several ores, usually combined with O or S. The sulphide, FeS_2, is commonly called *pyrite.* Iron is obtained from its ores by heating them in a *blast furnace.* In this big furnace coke or coal is mixed with the ore (usually an oxide of iron) and burned. A blast of air is forced into the furnace, and the fire (which burns all the time) gives a very great degree of heat. In this heat the ore is decomposed; its O unites with the C of the coke, and the iron in a melted state collects at the bottom of the furnace. From here it is drawn off into molds, and is called pig iron or cast iron. It is very impure.

Steel is a better grade of iron, which contains a fixed amount of carbon. It is commonly made by blowing air through a mass of highly heated pig iron. The impurities in the iron unite with the O of the air and are thus burned off, and then a known amount of carbon is mixed with the heated mass.

Plate V. Blast Furnaces

230. Sodium and Potassium. — The solid metallic elements Na (*sodium*) and K (*potassium*) are not found free in nature. Their *salts*, however, are very common and important. The elements may be separated from some of their salts. Neither is common outside of laboratories, and no great use is made of them. They are soft, waxy metals, lighter than water. Na acts upon water to decompose it, and K does the same, but more strongly.

Experiment 127. — Cut a small piece each of Na and K (the size of a small pea). Throw the Na on some water in a dish, being careful then to keep away from it. Next do the same with the K. What difference in these two cases? Try to explain how this difference proves that K acts upon water more strongly than Na (see § 206).

Of the salts of Na, NaCl is common and important; also Na_2SO_4 (sodium sulphate) and $NaNO_3$. Potassium carbonate, K_2CO_3, occurs in the earth, is absorbed by plants, and forms a part of wood ashes; KNO_3 (saltpeter) is an important salt of K. Na and K form strong bases or alkalis, — NaOH and KOH.

231. Calcium. — *Calcium* (Ca) is a solid metallic element; like Na and K, it is common only in compounds with other elements. Some of its compounds, however, are important and are found in large quantities. $CaCO_3$, *calcium carbonate*, occurs widely in the earth; in different forms it is called limestone, marble, or chalk. $CaSO_4$, sometimes called *gypsum*, also occurs in the earth; when heated it forms a white powder, — plaster of Paris. The oxide of calcium, CaO, is called *lime;* it is used

in making mortar and plaster. Ca is a base-forming element, the base being calcium hydrate, $Ca(OH)_2$.

232. Mercury.—The element *mercury* (Hg) is a metal, which is a liquid at ordinary temperatures. It is sometimes called quicksilver. It occurs free in rocks, and also as the sulphide (HgS). The metallic Hg is a heavy liquid, 13.6 times heavier than water. It is used in thermometers and barometers; also in forming the reflecting surface of mirrors. It dissolves several metals, and for this reason it is used in separating silver and gold from their ores.

Hg forms several salts, among them two chlorides, —HgCl and $HgCl_2$. HgCl, mercurous chloride, is called *calomel* and is used in medicine. Mercuric chloride, $HgCl_2$, is called *corrosive sublimate;* it is used as a disinfectant to kill bacteria. Hg is a poison, as are some of its compounds.

233. Other Metallic Elements. — The metals *copper* (Cu), *lead* (Pb), *tin* (Sn), *zinc* (Zn), *silver* (Ag), and *gold* (Au) are familiarly known to us. Cu, Ag, and Au occur free in nature; Cu and Sn occur as oxides; Cu, Pb, Zn, and Ag occur as sulphides, and Zn as a carbonate. These metals are in common use, and we can easily think of the uses of each. Cu and Zn form *sulphates* that are common, and Pb forms lead carbonate,—$PbCO_3$, known as *white lead* and used in making paint. Silver easily forms the *sulphide* Ag_2S; as there is nearly always a little S in the air, and always some given off in the perspiration from the body, silver articles become coated with Ag_2S and are said to "tarnish."

The metal *aluminium* (Al) is a very important element; it occurs as a part of some of the most abundant kinds of rocks. As a metal, Al is silver-white, strong, but very light in weight. The oxide of Al, Al_2O_3, occurs in nature as sapphires and rubies; it is also powdered and used for polishing, being called *emery*. Common *alum* is a sulphate of Al and K, $AlK(SO_4)_2$.

234. Silicon. — The element *silicon* (Si) never occurs free in nature, though in compounds it is very abundant in the earth. The most common compound, SiO_2, is called *silica* or quartz; it is a white or colorless rock, and in a finely broken form it is white sand. *Silicates* are salts of silicic acid, H_2SiO_3.

QUESTIONS

1. What sort of a substance is O? In what does it occur? How common is O? What two important uses does it serve?

2. Describe the element H. Why is H used in balloons? What chemical property makes it a very important element? In what substances does it occur?

3. In what does N occur? Is it an active element? What purpose does it serve in the air?

4. Name substances that are nearly pure carbon. How are these substances made? In what sorts of matter is C very important? Name two different crystalline forms of C.

5. Describe the element S. Where does it occur in nature, and in what form? What important compounds contain S? For what is free S used?

6. For what chemical property is P a valuable element? Explain its use in matches. Why cut P under water? Why not breathe its fumes?

7. Describe chlorine. What important compounds does it form? What uses are made of the element?

8. In what form does iron occur in the earth? What is the symbol for iron? How is iron obtained from its ores? What is pig iron? How is steel made?

9. Name salts of Na that are important; also salts of K. Explain the action of these elements upon water.

10. Name important salts of Ca that occur in the earth, and give common names for each. What is lime? For what is lime used?

11. Describe the element Hg. Name some of its uses. Name two of its common salts, stating the use of each.

12. In what form does each of these metals occur: Cu, Ag, Au, Pb, Sn, Zn? Name uses of each.

13. Describe the element Al. In what forms does it occur? What familiar compounds does it form?

14. In what form does Si largely occur? What is its most common compound? What is a silicate?

SECTION II

COMPOUNDS

235. Water. — *Water* is a compound of *hydrogen* and *oxygen;* its molecule contains two atoms of H and one atom of O, its symbol therefore being H_2O. Water is a most important compound, occurring not only in rivers, lakes, and oceans, but in the earth and the atmosphere (as vapor). Water is evaporated from the ocean, etc., and taken into the air as vapor; here it is condensed and falls to earth as *rain.* Some of this water sinks into the earth, flows along on hard rock as underground streams, and later comes to the surface again through springs or wells. *Mineral waters* are found in streams that dissolve some of the rock through which they flow. Rivers carry much material from the surface of the land to the ocean; this has been going on for so long that

the ocean water contains nearly 3% of mineral salts in solution. A large part of this dissolved matter is common salt ($NaCl$); the limestone ($CaCO_3$) in ocean water furnishes material for the shells of many small sea animals.

FIG. 134

In chemistry H_2O is of great value. It dissolves more different things than any other liquid, and as it is a *neutral* compound (not acting chemically upon the substance dissolved in it), water is a very useful *solvent*. To plant life H_2O is of first importance. Plants absorb large quantities of water through their roots; in their leaves and bark some of it is combined with carbon, making the great bulk of the solid matter. Water is hardly less important in animal life. It is present in nearly all foods, and all parts of the animal body contain a great deal of it.

Experiment 128. — Arrange apparatus for making H, as in Experiment 121. Heat the glass tube and draw it out to a small opening (Fig. 134). Into the test tube put Zn and HCl to make H. When the gas has flowed a few seconds, collect some in a small test tube (by holding the tube mouth downward over the end of the glass delivery tube); touch a lighted match to the gas collected in this small test tube. If a slight explosion occurs, wait a moment and then repeat; if the gas only burns quietly, then light the gas escaping from the delivery tube. This gas is H, now burning in air (containing O).

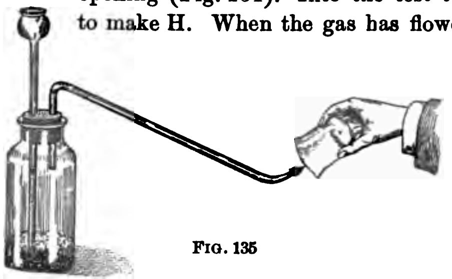

FIG. 135

At once hold a cool glass beaker or tumbler over the flame (Fig. 135) and note the condensing of water vapor upon it. This water vapor is given off when the H unites with the O, — $H_2 + O = H_2O$.

236. Sulphuric Acid.—*Sulphuric acid*, H_2SO_4, is made in great quantities by the union of the elements of SO_2, H_2O, and O. Being a very strong acid, it is used to break up the salts of many other acids, setting those acids free. In this way HCl is made from NaCl, HNO_3 from $NaNO_3$, etc. H_2SO_4 forms with different metals an important group of salts called *sulphates*.

237. Carbon Dioxide. — Whenever *carbon* is burned in a good supply of air, a gas called *carbon dioxide* (CO_2) is formed. CO_2 is a colorless, odorless gas; it is heavier than air, and is sometimes called *carbonic acid gas*. In the earth CO_2 occurs widely in *carbonates*, chiefly as $CaCO_3$ (limestone, marble, etc.). It is given off, in its free gaseous state, from burning wood, coal, kerosene, illuminating gas, etc.; also from the lungs of animals, mixed with the air breathed out. Carbon dioxide occurs (in a very small quantity) in the atmosphere, where it forms an important part of the food of plants. The gas which causes the "lightness" of bread and cakes is generally CO_2, and the same gas causes the effervescence of soda water and bottled tonics.

Experiment 129. — Into a large test tube put a few bits of marble, and add HCl. Stop the test tube, running a delivery tube to the bottom of a loosely covered jar, as in Experiment 125. When the gas has flowed freely for two or three minutes remove the tube from the jar, carefully covering the latter. In this way fill two jars. The gas is CO_2. $CaCO_3 + 2\,HCl = CaCl_2 + H_2O + CO_2$.

Experiment 130. — Carefully balance a thin glass beaker on a delicate set of scales. The beaker of course contains air. Now pour the CO_2 from one jar into the beaker, as in Fig. 136. If the balance is not changed, repeat the experiment carefully. Compare the weights of CO_2 and air.

Experiment 131. — Into the other jar of CO_2 thrust a lighted stick or taper, and note what happens. What does this show with regard to CO_2? Try to explain why the gas should behave in this way.

FIG. 136

Carbon dioxide is not a direct poison to animals, but because it does not supply the free O that they must breathe, animals cannot live in it. For the same reason it is injurious to man. Oil and gas heaters give out large quantities of CO_2, using up the O from the air; they should not be used in rooms unless a constant supply of fresh air is possible. CO_2 neither burns nor supports combustion.

When C is burned with a *poor* supply of air, another gas is formed, called *carbon monoxide* (CO). This gas is very poisonous to man, even in small amounts. It is often formed in coal fires, from which it may be given off; hence the danger of sleeping in rooms with a coal fire.

238. Ammonia. — *Ammonia* is a compound of N and H, its symbol being NH_3. It is formed when certain animal matter decomposes in air, though it is generally

formed when coal is distilled in making illuminating gas. NH_3 is a *gas*, but it dissolves very easily in water. A solution of NH_3 in water forms NH_4OH, ammonium hydrate. This is a strong alkali; somewhat weakened with more water, it is used as "household ammonia." Two salts of this base are common, — NH_4Cl, familiarly called sal ammoniac, and NH_4NO_3, ammonium nitrate. A solution of sal ammoniac in water is used in many kinds of voltaic cells.

239. Cellulose. — *Cellulose* may be described as the chief substance which makes up the structure of plants. It is found in many different forms, though its chemical composition does not change. All wood fiber, trunks of trees, their branches, roots, stems, veins of leaves, and parts of fruits are composed largely of cellulose; also such fibers as cotton, flax, and hemp. The substance cellulose is a carbohydrate (§ 219) having the symbol $C_6H_{10}O_5$. It is formed by the activity of the plants, largely from the H_2O and CO_2 that the soil and the atmosphere furnish.

240. Starch. — *Starch* is a carbohydrate having the symbol $C_6H_{10}O_5$. It is made by the action of plants, and is found throughout the vegetable world; seeds of all sorts contain starch, and some plants store up large masses of it, as sago and tapioca. Starch is prepared in large quantities from corn and from potatoes. It forms an important food for man, both in its prepared state and as cereals, — barley, oats, wheat, rye, rice, etc. In cold water, starch is usually not soluble; but in hot water it partly dissolves, forming a paste.

Notice that starch has the same chemical composition as cellulose ($C_6H_{10}O_5$). The chief difference between the two compounds is that cellulose is the actual substance of which the plant is composed, while starch is food stored by the plant for some future use. Thus seeds sprout, and the young plant grows for a short time by using the starch stored in the seed. The starch in a potato serves the same purpose.

241. Cane Sugar. — Common *sugar* occurs in several vegetable substances. It is generally obtained from sugar cane or beets. The cane or beet is usually cut up and bruised under water, the sugar being dissolved out; the solution of water and sugar is drawn off and boiled to a syrup. As this syrup cools some of the sugar forms in crystals; these are dried and crushed to make granulated sugar. The liquid that remains is boiled over, and again cooled; the crystals that now form are called brown sugar. After boiling the liquid two or three times more, no crystals will form and the syrup is then called *molasses*.

Cane sugar is a carbohydrate, its symbol being $C_{12}H_{22}O_{11}$. Its uses are too well known.

242. Dextrose. — Many fruits, such as grapes, plums, peaches, etc., owe their sweetness to another carbohydrate, *dextrose* ($C_6H_{12}O_6$). This substance is sometimes called *glucose*, *grape sugar*, etc. It can be made from cane sugar and is made in large quantities from starch. Dextrose is about three fifths as sweet as cane sugar. In fruits it forms an easily digested food. Confectioners use a great deal of the dextrose that is made from starch.

243. Alcohol.—Common *alcohol* (C_2H_5OH) is formed when dextrose or grape sugar ferments (§ 267). Hence it often appears when fruit juices are allowed to stand for some time. As a *solvent*, alcohol is much used in making varnishes, tinctures, perfumes, and drugs. It is useful in medicine because it stimulates the action of certain parts of the body; but a continual use of alcohol in any quantity is injurious. It burns with a hot, smokeless flame, being thus useful in several of the arts.

244. Fats and Oils. — *Fats* and *oils* are *salts* formed by the union of *glycerin* with different acids. Fats are solid substances, and occur usually in animal matter. Oils are liquids; they occur in both plant and animal matter. The acids that may unite with glycerin to form fats or oils are called *fatty acids.*

245. Soap. — A *soap* is an *alkali salt of a fatty acid.* Soap may be made by boiling fats together with an alkali (NaOH or KOH). The fats break up into their acids and glyceryl, the metal of the alkali uniting with the acid to form soap, and glycerin being given off. Thus soap is a salt of the metal Na or K with an acid obtained from a fat.

Soap acts upon the oily matter that is mixed with dirt on the skin or on fabrics; the oil is broken up into tiny particles that may be washed away by water, carrying the dirt with them. Water alone could not do this, because fats and oils do not dissolve in it. Many kinds of soap contain much free alkali; this renders them effective for cleansing, but often injurious to certain fabrics.

QUESTIONS

1. Of what is water composed? What is its symbol?

2. What are mineral waters? Why is ocean water salt?

3. Of what use is water in chemistry? Why is water a valuable solvent? State what you can of the importance of water in living bodies.

4. What is the symbol for sulphuric acid? How and why is sulphuric acid used in obtaining other acids? What is a sulphate?

5. How is carbon dioxide formed? Describe the compound. Name any common occurrence of carbon dioxide. Is CO_2 useful to plants? Is it useful to animals?

6. What is the objection to oil stoves and gas heaters in a room? Does CO_2 support combustion?

7. Under what conditions is carbon monoxide formed? Why is it more dangerous than CO_2? State the danger from coal stoves.

8. Of what is ammonia composed? What is the substance that is commonly called "household ammonia"? Name two salts of NH_4OH.

9. What is cellulose? State its symbol. Name parts of plants that are composed largely of cellulose.

10. Of what is starch composed? How is it made? Where is it found? Of what use is starch in seeds? Of what use in other parts of plants? What is the use of starch to man?

11. From what is cane sugar obtained and by what means? What is its symbol? What is molasses?

12. Where does dextrose occur? What other names are given to it? From what other compounds can it be made?

13. State uses of common alcohol. How is it formed?

14. What are fats and oils? Where is each found? What is a fatty acid?

15. What is a soap? Explain how soap is formed. Show the action of soap in cleansing things. Why does not water alone serve as well?

SECTION III

MIXTURES

246. Air. — The *air* is a mixture of gases, the quantities of which may vary somewhat. Pure air usually contains about *four fifths nitrogen* and *one fifth oxygen*, besides a very small amount of *carbon dioxide.* In the atmosphere there is also more or less *water vapor* all the time, the quantity varying greatly at different times and places. These four substances, N, O, CO_2, and H_2O, are each of some important use in the air; but there are also other gases, such as H, Cl, H_2S, NH_3, etc., which mix with the atmosphere in very small amounts now and then. The quantity of such impurities in the air is generally greater in cities, near factories or chemical works, near marshes and swamps, in mines, etc. Air in the country or over the sea is usually more nearly pure, though no strict rule can be stated.

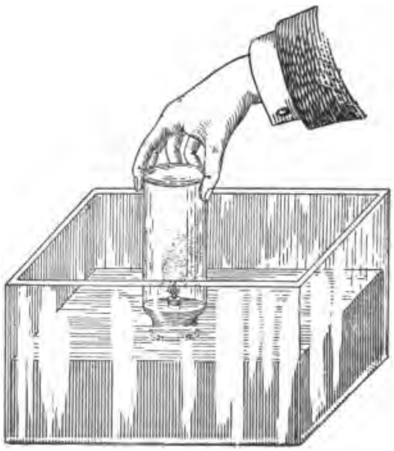

FIG. 137

Experiment 132. — Float a cork on water in a large vessel. Place a bit of P on the cork and light it; at once cover the cork with a large jar, as in Fig. 137, holding the mouth of the jar under water all the time. Allow the P to burn as long as it will,

carefully holding the jar. As the P burns (combining with O), the oxygen that was in the jar is used up, leaving the nitrogen nearly pure. The O combines with the P, the compound then being dissolved in the water. Thus the air in the jar loses from its total volume the volume of the O that was in it at first, and the water rises into the jar to take its place. Compare the volume of water that so rises with that of the gas still left in the jar. Of what is this gas largely composed now?

Experiment 133. — Carefully cover the jar under water; then lift it out and set it right side up on the table. Carefully uncover, at once thrusting a lighted splinter into the jar which is now filled with N. Does N support combustion?

The use of O in the atmosphere is to help support animal life, and to support combustion. Nitrogen, being very inactive, serves to check too strong an action of O; in an atmosphere of pure O fires would burn beyond control and animals could not live. The use of CO_2 in the air is to supply to plants the C that they need in making starch and cellulose. Water vapor in the air serves to temper the climate of some places, and is very important in furnishing rain. Without evaporation and rainfall the soil would everywhere become dry and the water would slowly drain from the land into the ocean.

247. Soil. — The earth is thought to be composed of solid rock. A great deal of its surface is covered with a layer of loose earthy matter called *soil*, which varies in thickness from an inch or two to several hundred feet in some places. On the average the soil is but a few feet deep. Soil is made of tiny *particles of rock* that have been worn off from the solid rock mass in different ways. As the kinds of rock that have been thus worn are many, so we find many different kinds of

soils. In many places decayed plant and animal substances have mixed with the soil, making more or less change in its composition.

The soil is very necessary to plant life. It allows the roots a good support; it holds moisture which the plant may slowly absorb; and it supplies small amounts of mineral matter, which is dissolved by the water and so taken into the plant structure.

248. Earthenware and Porcelain. — *Clay* is a kind of soil that contains a large quantity of aluminium silicate

FIG. 138

(§ 234). Clay may be moistened slightly and then molded into different shapes. If it is then baked in a furnace for some time the silicate becomes hard so that the vessel will keep its shape. In this way *brick* and vessels of *earthenware* (Fig. 138) are made.

Sometimes the aluminium silicate is found pure. If this be treated similarly to the clay, a finer grade of ware will be made; this is called *porcelain*.

249. Glass. — *Glass* is a mixture of silicates of two or more metals, — usually Ca, Na, K, Pb, Al, or Fe. It is

formed by heating *white sand* (silica, SiO_2) together with a compound of each of the metals to be used. Sand alone will not melt, but when heated with these other compounds they all melt and unite together, forming the silicates. This heated mass must then be cooled slowly, to make the glass as tough as possible.

The kind of glass formed, depends upon what metals are used. *Window glass* is a silicate of Ca and Na; *bottle glass* is a silicate of Ca, Na, Al, and Fe; glass used for *lenses* is a silicate of K and Pb. Very few substances act upon glass; air does not affect it, and liquids do not generally pass through it. For these reasons it is very useful as material from which to make bottles, jars, and other vessels. It is also one of the very few transparent solids that are common. Its importance is great.

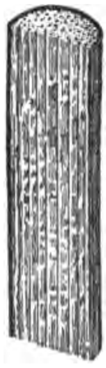
FIG. 139

250. Wood.—In general, *wood* is made up mostly of cellulose; the chief elements that it contains are therefore C, H, and O. Mixed with the cellulose are usually small quantities of mineral salts; these are left as ashes after wood is burned. Living wood always contains some water; and many kinds of wood contain other substances, such as oils, acids, pitch, resin, balsams, etc.

The cellulose in wood usually occurs in the form of *fibers*. In a cornstalk the fibers may be seen singly (Fig. 139), but they are more commonly grouped together in masses. The sap flows in spaces between the masses of fibers.

Experiment 134. — Secure a stick of oak wood, cut for a stove. Split it lengthwise; examine the freshly opened surface, using a microscope if possible. Can you see fibers? Do you see groups of fibers? Examine the end of the stick, looking for masses of fibers. Do you see the openings for the sap?

Experiment 135. — Put some bits of dry wood into a test tube and apply heat (Fig. 140). When the wood is thoroughly black, cease to heat it. Examine the remains. What is left in the tube and what has gone from the wood?

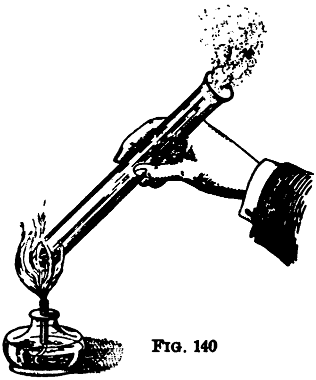

FIG. 140

251. Cotton Cloth. — Several plants — cotton, flax, and hemp — produce growths of fine fibers that may be easily separated. These fibers are twisted together to form rope, twine, and small threads. Threads of cotton or linen are woven together to form different sorts of *cotton* and *linen* fabrics. Plant fibers of this sort are the same in chemical structure as the fibers of wood; they are therefore cellulose.

252. Paper. — *Paper* is a mass of fibers very firmly pressed together. The fibers are obtained from cotton or linen *rags* and from *wood pulp* (a mass of short separated wood fibers).

To make paper, the rags are cleansed and then torn and shredded into tiny fibers by machines. Water is then added to the mass of fibers, so that the mixture easily flows. This mixture is poured out upon a flat surface, made so that the water may partly drain out, leaving

the fibrous mass spread evenly. An endless strip of cloth now picks up this fibrous mass, carrying it through several rollers. After passing through these, the paper is strong enough to go on through several more rollers without the cloth. The rollers are heated, and they press the fiber so firmly together that the mass becomes paper. Wood pulp is often mixed with the fibers from rags; some cheaper papers are made largely of wood pulp. Since it is made from wood and cloth fibers, paper also must be mostly cellulose.

Experiment 136. — Into one crucible put a mass of cotton threads, and into another some bits of paper. Cover each substance with a little dry sand, heat for a few minutes, and examine.

253. Coal. — Millions of years before man appeared on earth plants grew upon its surface. In some places large masses of trees, leaves, ferns, and other plant forms were piled up as they died, and were later covered by layers of soil and rock. These slowly decomposed, much of the gaseous part of the wood passing off, but the *carbon* remaining. In time these masses became hard, and to-day we find them in the earth as *coal*. Thus we see that coal contains the same elements that are found in wood, but the gaseous elements are much less in quantity and the C largely remains.

FIG. 141

Anthracite contains more carbon and less of other elements than soft coal. Some anthracite is over nine tenths carbon; it is the hard kind, such as is burned in

stoves (see Fig. 141). ***Bituminous coal*** is a softer variety. It contains more gases, burns at a lower temperature, and shows much more flame while burning than does hard coal.

254. Illuminating Gas. — If *soft coal* (bituminous) be heated to a high degree *without any supply of air*, the coal will be *decomposed*, its elements combining and mixing with each other to form new substances. The solid substance that remains is nearly pure C; it is called *coke*. The liquids unite in a mixed mass called *coal tar*. The gases that are given off are first passed through water, which dissolves the ammonia (NH_3) and thus removes it. The gases which remain in the mixture form *illuminating gas*. This contains some free hydrogen and some compounds of hydrogen and carbon. So we see that illuminating gas contains largely the elements C and H, both of which burn in air.

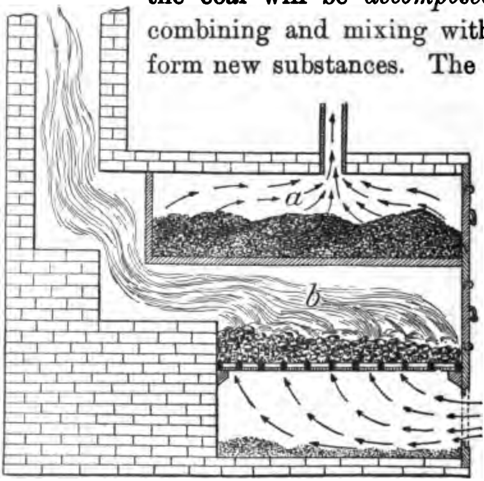

FIG. 142

The process is carried on in gas works. Coal is put into large iron retorts (*a*, Fig. 142) and heated by a

fire, *b*, placed underneath. Note that the coal itself is not burned but only heated without air until it is decomposed.

255. Petroleum. — *Petroleum* is an oily liquid found in the earth in some places. Pennsylvania and Texas have large oil fields. Petroleum contains many *hydrocarbons* (§ 218). Among the useful mixtures obtained from it are *kerosene*, *benzine*, *gasoline*, *naphtha*, and *paraffin*. Candles are commonly made from paraffin. Note that each of these substances contains largely the elements C and H.

256. Coal Tar. — In the process of making illuminating gas from coal, a thick black liquid called *coal tar* is formed (§ 254). This liquid has been found to contain a great number of compounds, so that coal tar is now the source of many common and important substances. Among these we may mention phenol, or *carbolic acid*; *saccharine*, a substance that is far sweeter than sugar; *aniline dyes* of many shades; and various *essences* and *perfumes*. The compounds found in coal tar contain chiefly the elements C, H, O, and N.

257. Explosives. — Gunpowder and other *explosives* are mixtures of such substances as may easily and quickly act upon each other so as to produce a large volume of *gas*. Explosives are generally either solids or liquids. Under a slight impulse (a spark or a sudden jarring) they quickly form into gases. These gases naturally take up far more room than the solid or liquid mass, and in *expanding* to their natural volume they exert great force.

Gunpowder is a mixture of saltpeter (KNO_3), carbon, and sulphur. Upon exploding, the gases N and CO_2 are set free. *Gun cotton* is a nitrate of cellulose chiefly. Glycerin also unites with HNO_3, forming a nitrate known as *nitroglycerin.* Nitroglycerin is a pale yellow liquid, highly explosive. It is used in making *dynamite* and some other explosives. Note that these substances all contain some *nitrogen;* because N is so inactive it forms compounds that easily break up and set the N (gas) free.

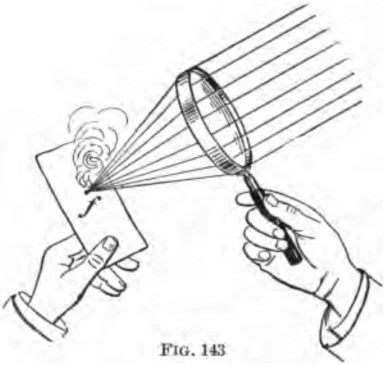

FIG. 143

Experiment 137. — In a mortar mix 12 grams KNO_3, 2 g. of C (charcoal), and 1½ g. of S. When thoroughly mixed, put a small amount on a piece of metal and touch it with a lighted match. Notice how it burns. The mixture is gunpowder. Why does it not explode with a loud report? Try to burn some gunpowder by converging the sun's rays upon some one spot, as in Experiment 94 (see Fig. 143).

258. Foods. — *Animal bodies* are made up of the same elements that compose matter in general, and only a few of these elements are present in any quantity. Since animals grow by taking in *food*, we can get a good idea of what elements are most needed by studying the foods used. Man is supplied with food that is largely of either animal or plant growth; but since the animals eat either plants or other animals that may live

upon plant growths, we see that nearly all of our food comes from the soil in the first place.

Man's foods may be divided into five general classes. First of all is *water*, which is needed in all parts of the body, and of which man uses a large amount. Next in quantity are the *carbohydrates* (§ 219) composed of C, H, and O; these supply energy and heat to the body. *Proteids* (§ 220) contain C, H, O, and N; they serve to build up muscle and other parts. Small quantities of *fats* serve to give energy to the system. Last of all are the *salts*, of which many occur in small quantities in other foods. The elements P, Cl, S, Ca, Na, K, Fe, etc., are taken on in slight amounts as salts.

259. Fuels. — The substances commonly used as *fuels* have already come to our attention; among them we recall wood, coal, illuminating gas, kerosene, gasoline, naphtha, benzine, and alcohol. Other things less commonly used as fuels are paper, rags, straw, and peat (partly decomposed vegetable matter). In all these substances note that the elements *hydrogen* and *carbon* are present; both of these burn in air (*i.e.* combine with O).

QUESTIONS

1. What four substances does air usually contain? State the uses of each of these. In what proportion does the N and the O occur?

2. Of what is the soil generally composed? By what different means may it have been formed? Name any common uses of the soil.

3. How are earthenware vessels made? Of what is porcelain made?

4. What is glass? Of what substances is glass made? How are these compounds treated to form glass? Name as many uses of glass as you can. What two properties make it valuable?

5. Of what substance is wood largely composed? What elements are present in this substance? Name other things that occur in some woods. Of what are ashes formed?

6. From what is cotton cloth made? What then is the chemical composition of cotton cloth, *i.e.* what elements are present?

7. Of what is paper made? Describe the process of making paper. What elements does it contain?

8. Of what is coal formed? How was it formed? What element constitutes the larger part of hard coal? What other elements are present? Distinguish anthracite and bituminous coal.

9. Describe the making of illuminating gas. What other substances are formed at the same time? Of what elements is illuminating gas largely composed?

10. What is petroleum? What substances are obtained from it?

11. Name some important substances that are formed from coal tar.

12. What sort of a mixture is an explosive? Show how explosive mixtures may be used to exert great force. State the composition of gunpowder; of gun cotton; of nitroglycerin.

13. What are the five classes of foods used by man? Name some elements that are common in the body. Of what use are carbohydrates in the system?

14. Name some common fuels. What two elements do they all contain?

CHAPTER X

COMMON CHEMICAL PROCESSES

260. Combustion. — *Combustion is a chemical union which takes place rapidly, giving off light and heat.* The word *fire* is commonly used instead of *combustion.* Two things are necessary in order that combustion may take place — a substance to burn (called a *combustible*) and a substance with which it may unite. The latter substance is said to *support* the combustion. We have learned that the things commonly burned as fuels contain the elements C and H (§ 259); also that the great supporter of combustion in the air is O (§ 222). With these facts in mind, it will be seen that the most common fires are simply *the rapid union of carbon and hydrogen with oxygen.* The compounds formed by this union will be carbon dioxide (CO_2) and water vapor (H_2O).

Now it is well known that in order to make any substance burn, *heat* must be applied. In other words, oxygen will not easily unite with other substances unless their temperature be raised. The temperature at which different substances will burn in air varies greatly; carbon, for example, needs a greater degree of heat than hydrogen, while matches containing phosphorus may be sufficiently heated by simply rubbing them. When we wish to start a fire, however, we do not heat the whole mass that is to be burned, but only

a small portion of it. This part burns, *giving off heat;* thus the parts right around it become heated until they also burn; and in this way the whole mass is finally heated and burned.

We have seen that in order for any substance to burn in air, it must be heated and constantly supplied with oxygen. Clearly, then, a fire may be stopped by cooling the burning mass or by cutting off the supply of oxygen (or air). Water is commonly applied, and it serves both purposes; but water is not always the best thing to use. Chemical fire extinguishers are of value when the fire is small; they are usually devices for making a large amount of CO_2 on the spot—and CO_2 does not support combustion. The most effective way to stop a fire when first started, is to cover it closely with rugs, clothing, earth, flour, or any solid which does not easily burn; in this way the air is kept away and the fire is "smothered."

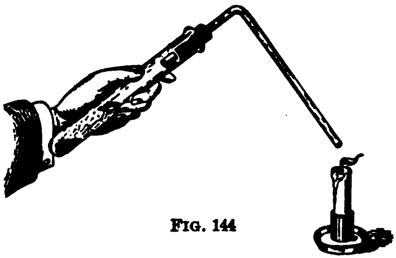

FIG. 144

Experiment 138.—Using a long or circular oil burner, turn the wick up just above the metal and light it at one point. Note the creeping of the flame along the wick as each part is heated from the burning portions.

Experiment 139.—Try to set fire to small quantities each of wood, alcohol, charcoal, sulphur, kerosene, phosphorus, hydrogen, soft coal, etc. (To use alcohol and kerosene, pour a few drops on a flat piece of wick.) Roughly compare the temperatures at which these substances burn. Other things could be used. Be careful with phosphorus, alcohol, kerosene, etc.

Experiment 140. — Into a large test tube fit a bent delivery tube (of small size), as in Fig. 144. Put bits of marble into the test tube and pour upon them strong HCl, so as to make a good flow of CO_2 (Experiment 129). Direct this stream of CO_2 gas upon a candle flame or a small fire made of chips. Note the effect, and explain.

Experiment 141. — Cut holes in a piece of cardboard and fit it into a small glass chimney. Stick a lighted candle on the card (Fig. 145). Now cover the chimney tightly at the top for a moment. Light the candle and set the chimney upon some flat surface that will close it at the bottom. Explain.

FIG. 145

261. Explosion. — An *explosion* is a sort of combustion that takes place very rapidly in a confined space. Two or more substances that may easily unite are mixed together; a mere spark at some point in the mixture will often cause action throughout the whole mass in a moment. If the mixture is *confined* in a small space, the gases that are formed by the chemical action will have so much larger natural volume that they will expand and burst the walls that confined them.

262. Flames. — A burning *gas* gives rise to a *flame;* burning *solids* usually glow and are *luminous* (§ 126), but without flame. When a solid substance, such as wood, burns with a flame, it is because the substance is being *decomposed* by the heat, and the gases that are given off cause the flames.

Experiment 142. — Make some H as in Experiment 121, using care in lighting the gas. The flame is usually somewhat colored by solid particles from the heated glass tube; but if the end be

fairly large or protected by a piece of platinum (Fig. 146), it may be possible to show that H burns with a colorless flame.

Experiment 143. — Pour a little alcohol over a few bits of charcoal (carbon) about the size of marbles. Pile these up on a glass or metal plate and light the mass. When the charcoal is well kindled, note that it glows and gives off light but no flame. What is being formed? Why is there no flame? Do not try this without the teacher's help.

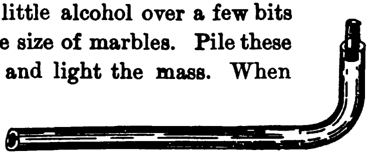

FIG. 146

The substances commonly burned to furnish *light* — illuminating gas, kerosene, gasoline, and paraffin candles — are made up mostly of the gas hydrogen and the solid carbon. Upon being lighted, the H burns and furnishes the *flame*, while the C in tiny particles becomes heated in this flame and *glows*, so that the whole gives off light. When a lamp "smokes" it is because the oil is being decomposed and the carbon particles given off faster than they can be heated and burned in the flame. In any case, *smoke* is made up of particles of matter that were not consumed in the flame.

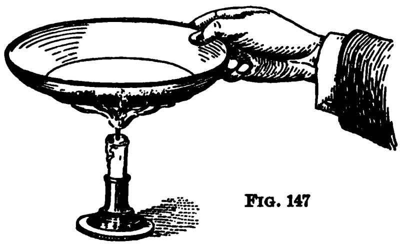

FIG. 147

Experiment 144. — Light a candle and trim it to give a good flame. Hold a piece of earthenware in this flame as in Fig. 147; note the deposit of soot. Of what is it composed? The solid object cools the flame so that it does not consume all of the C that is given off from the wick.

263. Fire. — As commonly used, the word *fire* may easily give us a wrong idea of its meaning. A fire is

only a process of combustion, and the word *fire* means all that *combustion* means, — the chemical union of different elements, together with the heat, flame, light, etc., that may occur in the process. A little thought will make the matter clear. The *chemical action* in common fires is between the elements H or C and O; the *heat* is given off as from any chemical union (§ 206); *flames* show that a gas (usually H) is burning; *light* is given off from glowing solid particles (commonly of C); *smoke* is a mass of solid particles that were not entirely burned; and *ashes* are made up of mineral matter that could not burn.

264. Oxidation. — We have learned that *oxygen* combines directly with many elements (§ 222), and that it does this rapidly if they be heated to a high enough degree (§ 260). Now it also happens that several elements will combine with oxygen even at the ordinary temperature of the air, but they do this very slowly. The process is called *oxidation;* the compound formed is called an *oxide.*

Experiment 145. — File a piece of iron till bright; dip it in water, remove it, and without even shaking off the drops of water, set it aside. In two or three days examine it, and tell what has happened.

Experiment 146. — Scrape a piece of lead till its surface is bright and clean, then set it aside. In a few days examine the lead, note its surface, and explain the change.

Most of the *metals* will combine directly with O; gold does not, and silver forms a sulphide rather than an oxide in air. The presence of *water* usually assists

oxidation. Iron rust, the most common of metallic oxides, is formed by the union of iron with oxygen, but this is always greatly helped by water, even if only the moisture in the air.

265. Oxidation in Animal Bodies. — We breathe air into the lungs for the *oxygen* that it contains. *Carbon* is taken into the body in the food that is eaten (§ 258), and is found all over the system. In the lungs O is separated from the air and is carried by the blood to all parts of the body. There it unites with the C which is already in those parts, and forms CO_2. This *chemical union* of the C with O gives off *energy*, as does any chemical union; the energy is used by the body, partly as *heat* to keep us warm, and partly as *muscular energy* so that all parts may move and do their work.

The CO_2 that is formed is carried to the lungs, where it leaves the body in the air that is breathed out. *Plants* take air into their leaves, separate the C from the O of the CO_2, *use the carbon* in making starch, and give out pure oxygen to the air again.

266. Decay. — Many substances, particularly of plant and animal matter, will *decay* after a time unless cared for in some special way. The signs of decay are many: the body is usually soft and easily crumbles; it is generally much smaller in size than before; and often an odor is given off. The smaller size is due to the fact that a large proportion of any animal or plant matter is of gaseous elements; these of course pass off when they are set free by decay. The odor is caused by gases that are formed; one of the most common of these gases is

hydrogen sulphide (H_2S), — a compound that is found in large amounts in eggs that have lost their usefulness.

Decay is a process of *decomposition* which goes on slowly and quietly. Its causes are not well understood in all cases, but it is thought to be sometimes due to very tiny vegetable forms called *bacteria*. These tiny bodies are too small to be seen without a powerful microscope; they are common in the air, the soil, and in water, as well as in various other substances. Heat generally kills them, and most kinds seem to work best in a good supply of oxygen. Fruits are often put up in jars while hot and at once covered tightly; in this way they may be kept for a long time without decaying. Fig. 148 shows several bacteria, greatly magnified. There are of course other causes of decay.

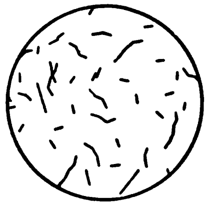

FIG. 148

267. Fermentation. — If apple juice is allowed to stand for a time, we know that alcohol may form in it and the juice becomes cider; similarly, grape juice may become wine, containing alcohol. Clearly a chemical change goes on in the liquid, and this change is called *fermentation*. It is caused by something that is present in the fruit juice, or that gets into it from the air. These things that may cause fermentation are called *ferments*.

Many different ferments are known, and they act upon many substances. One of the most common of ferments is *yeast;* it acts upon *dextrose* or grape sugar

(§ 242), breaking up the dextrose into *carbon dioxide* and *alcohol*. Since dextrose occurs widely in fruits, this sort of fermentation is very common. All sorts of alcoholic stimulants — wines, whisky, etc. — are made by allowing something to become fermented.

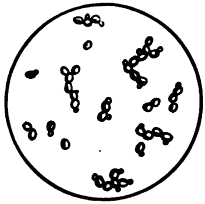

FIG. 149

Yeast is a very low form of plant; in its nature it is somewhat like bacteria. Fig. 149 shows a few bits of yeast, greatly magnified. It is found frequently in the air, from which it easily gets into many substances.

Other sorts of fermentation are common. Apple juice partly ferments and becomes cider; then another ferment acts upon the alcohol in the cider, changing that to an acid, so that the liquid becomes *vinegar*. The souring of milk is a process of fermentation.

268. Bread Making. — Yeast may be easily made to grow till it forms a large mass. This is commonly done by many cooks, who make what they call potato yeast; in this case the potato serves as a substance in which the yeast plant may grow. Cakes of compressed yeast may be bought of the grocer; these are masses which have been grown for the purpose in large quantities.

Bread is made of flour mixed with milk or water to form dough; yeast is added to "raise" the dough. Flour is largely *starch*. When the mass is put in a warm place the yeast acts upon the starch, changing it to *dextrose;* this is further acted upon, so that it ferments, forming alcohol and CO_2. The CO_2 cannot

escape through the dough, so it simply forms in bubbles, making the mass "light." In baking, the alcohol is mostly driven out and the heat stops any further action of the yeast.

269. Disinfection. — The *bacteria* of which we have studied are very numerous; there are also many different kinds. They are too small to be seen without a strong microscope, except in masses composed of many. Some kinds of bacteria are harmless and some are even useful, but a few kinds are known to be the cause of certain *diseases* in animals and man. These kinds are usually given off in some quantity from persons who are ill with such diseases; and as they may be taken into the bodies of other persons and there cause illness, it is important to try to kill the "germs."

The killing of these bacteria is called *disinfection.* Many methods are used. *Heat* is of great use, as a temperature of 100° C (boiling water) will destroy all common forms in a short time. All dishes and cloths used by the patient should be carefully boiled in water, and papers should be burned. *Fresh air* in the sick room is important, and *sunlight* kills many bacteria. For a liquid disinfectant, weak solutions of carbolic acid or of some chlorides are good, but nothing seems to equal a weak solution of *corrosive sublimate* in water (1 part in 1000). After all, the best way to avoid diseases is to keep ourselves clean and keep our general health at the highest. Many disease germs doubtless enter the body of a well person and do no harm because of his strong, healthy condition.

QUESTIONS

1. Define combustion. What is a combustible? In common fuels, what elements usually burn? What substance commonly supports combustion? Name the compounds generally formed by combustion of fuels in air.

2. How, in general, may we start combustion? How, after being started, does the process keep itself going on? By what means may combustion be stopped?

3. What is an explosion? Why is an exploding mixture able to exert so great force?

4. What sort of substances burn with a flame? How do solids burn? Show why flames are seen when some solids (*e.g.* wood) are burned. Explain the burning of such substances (*e.g.* kerosene, candles, etc.) as furnish light. What is smoke?

5. What is meant by the word *fire?* In common fires explain each of these: the heat, light, flame, smoke, and ashes.

6. Explain the meaning of oxidation. What substances commonly form oxides in this way? What is iron rust? Under what conditions is it usually formed?

7. What element in the air is needed by animals? What becomes of this element when it is taken into the lungs? With what does it unite? Where? What does this process supply to the body?

8. What is meant by decay? What sorts of substances usually suffer decay?

9. What is a ferment? Name a common ferment. When a ferment acts upon dextrose what is formed? How is vinegar made?

10. What sort of a substance is yeast? Explain the action of yeast in bread making. What gas is formed, and what is its use?

11. Explain how disease may be given from one person to another. What is meant by disinfection? What methods are useful?

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ANNOUNCEMENTS

A STUDY OF FOODS

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